NASA

FROM SPACESHIPS TO ORBITING STATIONS

1. Report No. NASA TT F-812	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle FROM SPACESHIPS TO ORBITING STATIONS Second Edition		5. Report Date December 1973
		6. Performing Organization Code
7. Author(s) A. Yu. Dmitriyev, V. P. Denisov, A. A. Yermilov, B. I. Zhelyabin, A. V. Kirsanov, I. L. Leonidov, V. A. Polyakov, A. A. Timonin and A. M. Tumanov		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address Scitran Santa Barbara, CA		11. Contract or Grant No. NASW-2035
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Ot kosmicheskikh korabley - k orbital'nymn stantsiyam, " 2nd Edition, Revised and Expanded, Edited by G. S. Narimanov, Moscow, "Mashinostroyeniye" Press, 1971, pp 1-113

16. Abstract This book discusses the Soviet manned space program. The main stages of development of Soviet cosmonautics are considered, as well as the programs for the manned spacecraft "Vostok","Voskhod"and "Soyuz", and the orbital research station "Salyut". The construction and equipment of the spacecraft, and their use on the earth and in flight are described. A description is given of the first orbital space station of the "Soyuz" spacecraft, as well as its operation and the experiments performed when the crew changed from one spacecraft to another in open space. The development of methods for assembling a station and performing scientific studies, and also the scientific station "Salyut", on which the Soviet cosmonauts lived for several days are described. The book also discusses the future prospects for cosmonautics.

17. Key Words (Selected by Author(s))	18. Distribution Statement Unlimited - Unclassified

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	134	Domestic,$4.50 Foreign,$7.00

*For sale by the National Technical Information Service, Springfield, Virginia 22151

ANNOTATION

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The book also discusses the future prospects for cosmonautics.

Twenty nine illustrations.

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FOREWORD

Cosmonautics, embodying the most advanced achievements of world science and technology, is developing at an impetuous pace. /3*

Fourteen years ago, on 4 October 1957, the first Soviet artificial satellite announced to the world the beginning of a new era — the era of space flight. Since then hundreds of different artificial satellites have been launched, which daily move in space. Tens of manned spacecraft have measured off many millions of kilometers in the reaches of space. Man has bravely "walked" in open space, set foot on the surface of the moon, and is confidently overcoming the biological barrier of prolonged space flights.

A little more than ten years separate us from the launch of the first manned "Vostok" spacecraft, which completed one orbit around the earth. Spacecraft are now capable of spending many days in flight, while their crews carry out a large volume of scientific investigations and observations, of enormous practical importance for the national economy.

Automatic interplanetary stations in turn are penetrating deeply /4
into the secret reaches of the solar system. They were the first to investigate the moon, photograph the surface of Mars, penetrate the red hot atmosphere of Venus and transmit data to the earth on its composition. Automatic stations have brought back samples of lunar soil to the earth.

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*Numbers in the margin indicate pagination in the original foreign text.

1. THE MAIN STAGES OF SOVIET COSMONAUTICS /5

The 1960's have been characterized by the greatest achievements in many fields of human activity. The scientific thought and work of man have left far behind concepts that only recently seemed impossible. These achievements have been most vividly expressed in the investigation and conquest of space. The sixth decade of our century became a time of the genuine triumph of space rocket technology. Space research accomplished during this period with the aid of automatic equipment and manned spacecraft not only opened a qualitatively new stage in the development of space science, but also marked the beginning of a new epoch in the development of science in general.

During the period 1957-1961, the Soviet Union launched automatic stations for study of the earth and circumterrestrial space, the moon and distant space. As a result of these experiments, the basic systems of space rocket complexes were developed and the most valuable scientific data were obtained. Many scientific-technical collectives were formed in the Soviet Union, which are capable of solving the most difficult problems of cosmonautics, and a powerful industrial base was created.

At the beginning of the 1960's Soviet specialists solved the most complex problem — they created the first manned spacecraft. The era of manned space flights began. In the course of these flights, the /6 effects of G-forces and weightlessness, radiation and prolonged restriction in a cabin of limited volume were gradually investigated, step-by-step. Problems of a psychological nature, concomitant with complex space flights and emergence of man into open space, were studied. Special attention was devoted to determining the possibility of normal

human activity and to conducting scientific and technical investigations and experiments during these flights.

The rapid pace was enhanced by automatic means for investigating outer space. The equipment of artificial satellites became more complex and technically more perfect, and specialized scientific satellites were developed. Automatic interplanetary probes began to transmit rich information on the properties of circumsolar space.

The following main stages may be traced in the development of cosmonautics:

-- launch of artificial satellites (providing acceleration to orbital velocity -- about 8 kilometers per second);

-- launching of interplanetary probes (acceleration to escape velocity -- about 11.2 kilometers per second);

-- injection into geocentric orbits, flight and landing of manned spacecraft;

-- launching of automatic space vehicles on flights to the moon and planets, landing on the moon and creation of artificial lunar satellites;

-- development of reentry in controlled and ballistic variants for vehicles returning to earth at escape velocity;

-- emergence of man into open space and work outside the spacecraft;

-- development of processes for search, rendezvous and docking of space vehicles and spacecraft in both automatic and manned versions;

-- flight of man to the moon;

-- group flights of several manned spacecraft, forming a single system, and creation of orbital stations;

-- creation of automatic interplanetary probes which are returned to earth with the results of scientific investigations of the moon.

All these stages have been successfully covered by world cosmonautics. Our science and space industry have permitted the Soviet Union to be first in successfully solving most of the tasks of

cosmonautics.

At present, our achievements in space are an important indicator of the scientific, technical and economic development of the country. On the other hand, the program for conquest of space is predetermined by the requirements of science, the national economy and society as a whole. In accordance with this, several series of space vehicles have been developed in the Soviet Union.

The most numerous of them is the series of "Kosmos" satellites, which are carrying out an extensive program of scientific research. /7
Several tens of satellites of this type are launched annually, and their total number exceeds 400. The "Kosmos" satellites are conducting important scientific investigations of circumterrestrial space and radiation from the sun and stars, and are studying the earth's magnetosphere, the composition of cosmic radiation and radiation belts, the "breathing" of the ionosphere and distribution of meteor particles in circumterrestrial space. Interesting medical and biological experiments are being carried out on these satellites, which extend the boundaries of penetration of life into limitless space. Forming complete systems, satellites of the "Kosmos" series aid man in the solution of practical problems, contribute to the progress of science, and have actually passed into the ranks of permanently operating systems.

Some vehicles of the "Kosmos" series are being used to check the correctness of engineering solutions, development of the design elements of various spacecraft and methods of using them. Methods for automatic docking in orbit were tested with the aid of the "Kosmos" satellites, the "Meteor" and "Molniya" equipment was tested, and the possibilities of systems for heat regulation and provision of cosmonaut activity and many other complex assemblies of manned spacecraft were investigated.

Automatic satellites solve problems of great practical importance. The Soviet specialized scientific satellites of the "Proton," "Elektron,"

and "Polyot" series are known worldwide.

The continuously operating system of "Molniya" communication satellites provide 24-hour two-way telephone and telegraph communication over the entire territory of the Soviet Union. These satellites relay programs of the Central Television Studio to the extensive network of ground receiving stations of the "Orbita" system, due to which the programs of Moscow television have become accessible to most regions of Siberia and the Far North, Far East and Central Asia.

Another continuously operating system -- that of meteorological satellites of the "Meteor" series -- provides 24-hour observation of the weather phenomena of our planet. Many thousands of photographs of the earth's surface, transmitted by these satellites, are processed daily by the automatic ground complex and transmitted to the Hydrometeorological Center of the USSR. Daily weather summaries, as well as reliable long-term forecasting are made on the basis of these data.

Investigation of outer space acquires an ever more international character with each year. Artificial satellites of the "Interkosmos" series are launched periodically in the Soviet Union in accordance with the program for cooperation of the Socialist countries in the field of investigation and use of outer space for peaceful purposes. Scientific equipment, developed and prepared by specialists of a number of Socialist countries, is installed on board these satellites. Assembly and testing of this equipment immediately prior to launch, as /8
well as control of the flight of "Interkosmos" satellites, is accomplished by operational groups from among representatives of a number of countries. Simultaneously with the measurements carried out on board the satellites, observatories of the Peoples Republic of Bulgaria, the Hungarian Peoples Republic, the German Democratic Republic, the Republic of Cuba, the Mongolian Peoples Republic, the Polish Peoples Republic, the Socialist Republic of Rumania, the Soviet Union and the Czechoslovakian Socialist Republic carry out radio astronomical, ionospheric and optical observations according to a coordinated program.

Along with flights in circumterrestrial space, the study of the moon, planets and the various regions of the solar system occupies an important position in the Soviet space program. A leading role in these investigations is played by automatic vehicles. They are considerably more inexpensive than manned vehicles, and are capable of transmitting or bringing back to earth the most valuable scientific information, often from those regions which are completely inaccessible or difficult for man to reach. This, of course, does not exclude the participation of man in certain scientific investigations of distant space, the moon and planets of the solar system.

The enormous achievements of science, technology and engineering in the 1960's led to the creation of ideal means of electronics and radio engineering, automation, optics and computer technology. The dimensions and weight of scientific equipment have been reduced considerably, and the speed of computers and the capacity of electronic memory systems have been increased. This has been reflected in the creation of unique automatic vehicles for investigating outer space and planets of the solar system.

Automatic control machines have enormous possibilities in the Universe. With their aid, scientists obtained the first pictures of the lunar surface and information about physical conditions on the moon and Venus, and extremely rich scientific data which will undoubtedly be of great assistance in learning about the origin of celestial bodies and the evolution of the Universe.

Important scientific and technical problems were solved by the "Zond-5," "Zond-6," and "Zond-7" automatic probes, which orbited the moon and returned to earth. During these flights two variants were checked for landing space vehicles and returning to earth at the parabolic velocity. The "Zond-5" probe was the first to solve this problem upon return from a flight along the earth -- moon -- earth trajectory. The descent capsule of the "Zond-5" probe entered the atmosphere through a comparatively narrow corridor, and - passing

through along a ballistic trajectory - reached the Indian Ocean basin in the assigned region, having brought back to scientists photographs of the earth taken from space and the results of scientific investigations.

An even more complex scientific and technical problem -- controlled descent of the capsule which had orbited the moon -- was first solved /9 during the flight of the "Zond-6" probe. The reentry capsule of the probe, using a lift-drag ratio, flew more than 9,000 kilometers after first entering the dense layers of the earth's atmosphere and finally fired its retrorockets upon the second entry, landing in the calculated region of the Soviet Union. Controlled descent permits selection of the landing regions, as well as reduction of G-forces and heating of the capsule during its motion in the atmosphere.

The "Zond-7" automatic probe brought back to earth unique photographs of the lunar surface and our planet.

The most vivid example of the truly inexhaustible possibilities of automatic assistants to man is the flight of the Soviet automatic probe "Luna-16." During the course of the flight, the vehicle was injected into a selenocentric orbit, a number of maneuvers was made in this orbit and - using airborne radio aids for measuring flight speed and altitude, computing systems and the retrorocket system — made a soft landing on the lunar surface in the region of the Sea of Fertility. Drilling of the lunar soil, which was then reliably sealed in the return module, was carried out for the first time in the history of cosmonautics. On command from earth at the precisely designated time, "Luna-16" blasted off from the lunar surface, returned to earth along a ballistic trajectory and landed on the territory of the Soviet Union near the launch site. Thus, an automatic vehicle first brought back to earth a sample of rock from another celestial body.

The automatic probe "Luna-17" delivered the lunar excursion vehicle "Lunokhod-1" to the surface of the moon. For ten months

the Soviet lunar excursion vehicle traveled through lunar craters, transmitting to earth high-quality television pictures of the lunar landscape and data from various scientific investigations.

Automatic interplanetary probes "Venera-5" and "Venera-6" were launched in January, 1969, in accordance with the program. These vehicles, equipped with various types of scientific and measuring apparatus, made it possible to conduct new scientific investigations along the flight path and to obtain additional data about the atmosphere of Venus. The "Venera-5" and Venera-6" probes reached the planet in the middle of May 1969, having flown a distance of about 250 million kilometers. The automatic probe "Venera-7," after reaching the surface of the "morning star" on December 15, 1970, successfully carried out its flight program.

Further penetration of man into space depends to a great extent on solving the problem of life support during prolonged space flights. With this aim, a ground-based experimental complex of life-support systems, based on use of the most recent achievements of biology, technology, chemistry and medicine, was erected in our country. An experiment with participation of three test subjects was begun in this complex in November, 1967, and was successfully completed within one year. The experiment demonstrated the possibility of prolonged restriction of man in a pressurized cabin of limited volume and the use of a regenerative life-support system, and investigated the effect of certain factors of prolonged space flight on the human body and human efficiency.

The Soviet space program provides for careful stage-by-stage development of new systems under ground conditions and for conducting a large number of experimental investigations. New manned spacecraft and their systems, after being developed on the ground, are repeatedly tested in unmanned variants during space flights, and only after this are flights made with cosmonauts on board.

On January 14, 1969 cosmonauts V. A. Shatalov, B. V. Volynov,

Ye. V. Khrunov and A. S. Yeliseyev completed manual docking of the "Soyuz-4" and "Soyuz-5" spacecraft. An experimental space station was created for the first time, and transfer from one spacecraft to another was accomplished.

The group flight of the "Soyuz-6," "Soyuz-7," and "Soyuz-8" spacecraft, the unprecedented duration of the flight of the "Soyuz-9" spacecraft, as well as the complex of investigations on board the "Salyut" station were the next stages on the way to creating long-term orbital stations.

Successes in the solution of important scientific and technical problems not only open up important prospects for the further conquest and study of space, but also pose a number of completely new problems, related to the use and further perfection of space technology. The space environment is fraught with many still hidden dangers, which cannot be detected during one or several flights.

Flights of space vehicles of different design -- both Soviet and foreign -- contribute to discovery of these dangers and the related problems which arise, and to complex investigation and conquest of outer space.

/11

2. PROGRAMS OF THE "VOSTOK" AND "VOSKHOD" MANNED SPACECRAFT

Preparation for Human Flight into Space

Biological investigations during the flight of high-altitude rockets were being carried out in the Soviet Union even before the launch of the first artificial satellite, beginning in 1949. Several tens of experiments were carried out with flights of animals on rockets up to altitudes of 450 kilometers. The investigations established that both during flight and for a long period after return to earth, no serious changes of any kind were found in the organism of the animals. These investigations laid the basis for a systematic study of the effect of the space environment and flight factors on living organisms.

However, only biological investigations on satellites may provide a complete picture of the long-term effect of weightlessness and cosmic radiation on the organism. The first biological object in space was the dog Layka, which completed the flight on board the second Soviet artificial earth satellite.

The next step in preparing man for flight into space was creation of the "Vostok" launch rocket and tests and development of the spacecraft and its systems.

Five experimental satellite-spacecraft with experimental dogs on board were injected into circumterrestrial orbit in 1960 and 1961. The main purpose of these launches was to develop the on-board systems /12 of the spacecraft, to study the physical conditions of space along the route of the impending flight of man and to carry out an extensive complex of medical and biological investigations related to preparation for this flight. The flights of the experimental satellite-spacecraft simulated to the maximum extent possible the conditions and program of the impending flight of man into space. They were accomplished according to similar programs, with the same flight duration. A cosmonaut mannequin and a dog were in the capsule.

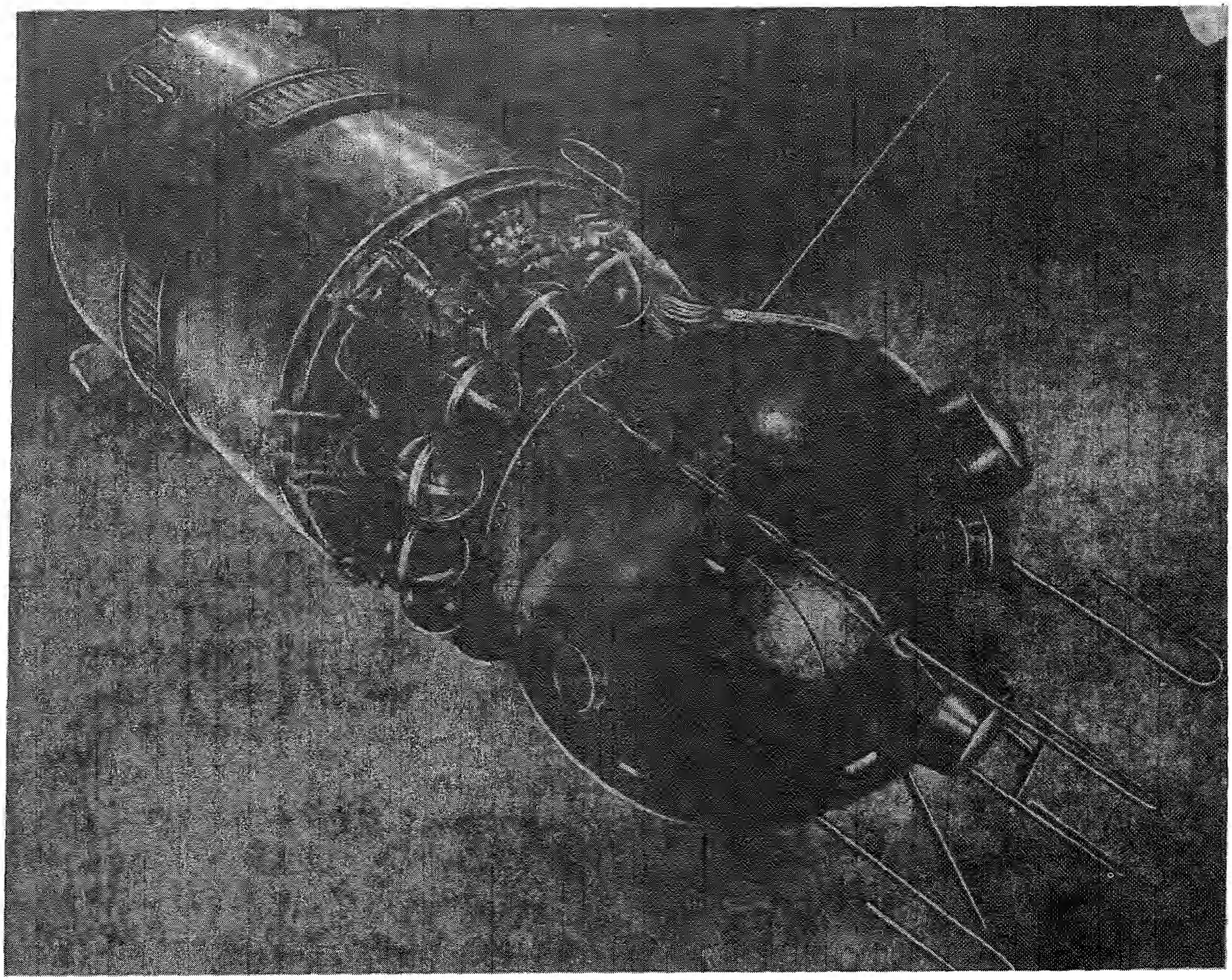
The experiments showed that the spacecraft fully met the requirements for maximum safety for human flight into space and provided for his normal activity and conditions for fulfilling the program of scientific and technical investigations. This was the stage immediately preceding the flight of man into space.

But long before this, extensive investigations on the effects of individual factors of space flight on the human organism were being carried out in the Soviet Union with the aid of various ground-based facilities. However, laboratory experiments in thermal vacuum chambers and centrifuges did not usually permit a complex analysis of their effects on living organisms, and the state of weightlessness in flying laboratories could not be long enough.

Development of various on-board systems was proceeding simultaneously with medical and biological investigations. Systematic and comprehensive verification and sequential development of individual systems and the spacecraft as a whole under both ground and flight conditions permitted the first flight of man into space.

THE "VOSTOK" PROGRAM

The first flight of man into space took place on April 12, 1961. The world's first cosmonaut was Soviet citizen Yuriy Alekseyevich Gagarin. The orbital flight of the "Vostok" manned spacecraft continued for 108 minutes, and the cosmonaut was in a state of weightlessness for 55 minutes. The flight showed that man could normally tolerate the conditions of space flight and return to earth. It was also demonstrated that man completely retains his efficiency during space flight.



The "Vostok," the world's first spacecraft.

THE "VOSTOK," THE WORLD'S FIRST SPACECRAFT.

The manned flight program on board the "Vostok" spacecraft, carried out during the period 1961-1963, consisted of six sequential launches. The flights of space heroes Yu. A. Gagarin, G.S. Titov, A.G. Nikolayev, P.R. Popovich, V.F. Bykovskiy and V.V. Tereshkova made an important contribution in the development of cosmonautics to knowledge of the secrets of space. Their names have been entered in history. /14

Each subsequent flight, based on the results and experience of preceding flights, was the next step in the conquest of space and made a contribution to the development of science and technology and led to an assault on new frontiers. But at the same time each flight confronted scientists and engineers with the necessity of solving new tasks and problems. What problems did the "Vostok" program solve? Completion of the first flight of man into space, spacecraft flights of many days' duration in preparation for creation of earth orbital stations and for future interplanetary flights.

The flights of different length by cosmonauts in the "Vostok" spacecraft revealed the possibility of active viability of man during space flight, operations were carried out on piloting the spacecraft, and various scientific and technical investigations and experiments were carried out. The cosmonauts retained good efficiency during flight, conducted astronomical, geophysical, meteorological and other investigations and experiments, observed the state of the cloud and ice situation on the earth and carried out movie and still photography.

The "Vostok" program was the foundation on which development of Soviet and world cosmonautics was based. The principal problems of spacecraft design for space flights were resolved during implementation of this program, and the basic elements of the flight plan were clarified.

The "Vostok" spacecraft consisted of a reentry capsule and an

instrument compartment. This layout of spacecraft construction was, as experience showed, rational with respect to weight, technologically efficient and convenient for arrangement of the on-board equipment. The reentry capsule with the cosmonaut cabin was made in the form of a sphere 2.3 meters in diameter and weighing 2.4 tons. The cosmonaut cabin contained three portholes, protected against the effects of high temperatures during the descent phase by heat-resistant glass, for conducting scientific observations during space flight. A special life-support system, maintaining normal pressure, specific chemical composition of the air, temperature within the range of 15-25°C and relative humidity from 30 to 70%, was installed in the spacecraft. The water and food supply and regenerative substances were calculated for a flight lasting up to 10 days.

The cosmonaut cabin was provided with adequate facilities and safety for human flight.

Although all systems of the spacecraft passed a complete and extensive cycle of checks and flight-design tests, a special pressure suit was used for additional insurance against possible unexpected events during flight.

Design and creation of the cosmonaut's seat was a very complex task. The seat provided for the safety of the cosmonaut during flight /15
and during the effects of G-forces. Various automatic devices, the space suit ventilation system, catapult and pyrotechnic devices, parachute systems, emergency supplies, including supplies of food, water, rescue and signalling aids, which the cosmonaut could use after landing, were installed in the body of the seat.

The spacecraft contained devices which ensured the flight and landing of the craft, functioning of the cosmonaut and fulfillment of the assigned flight program by him. The most important of them was equipment for monitoring the operation of the control systems and instruments of the spacecraft, radio equipment for communication between the cosmonaut and the earth, an automatic system for recording

data on operation of instruments, a radio telemetry system, equipment for monitoring the condition of the cosmonaut, equipment of the attitude control system, a radio system for measuring orbital parameters, a landing system, electric power supplies, the "Vzor" optical device for manual attitude control, television equipment and retrorockets. The cabin contained a pilot console with an instrument panel and a stick with a control unit for controlling the spacecraft. The cosmonaut was able to determine the position of the spacecraft above the surface of the earth with the aid of a miniature globe of the earth located on the instrument panel.

The equipment of the attitude control system included control instruments, actuating members and a solar sensor. Attitude control of the spacecraft in space during flight and descent could be accomplished both automatically and manually.

The state and well-being of the cosmonaut, the operation of onboard systems and the environment in the pilot's cabin were monitored continuously throughout the entire flight with the aid of many tens of sensors and the telemetry system. The television equipment installed in the cabin permitted the observation of the cosmonaut's activity.

The retrorocket and parachute systems installed on the spacecraft were used during the last leg of the flight for descent and landing. The retrorockets were used during reentry of the spacecraft.

Descent and landing were provided by the parachute system for landing the reentry capsule and by the individual landing system of the cosmonaut.

What measures were taken to ensure the cosmonaut's safety?

A special pressure suit protected the cosmonaut against an unexpected drop in cabin pressure.

An ejection seat with a jet booster guaranteed the safety of the

cosmonaut in case of failures during launch. One of two landing systems — either descent inside the cabin or by the individual parachute system of the cosmonaut — could be used during the final stage of flight.

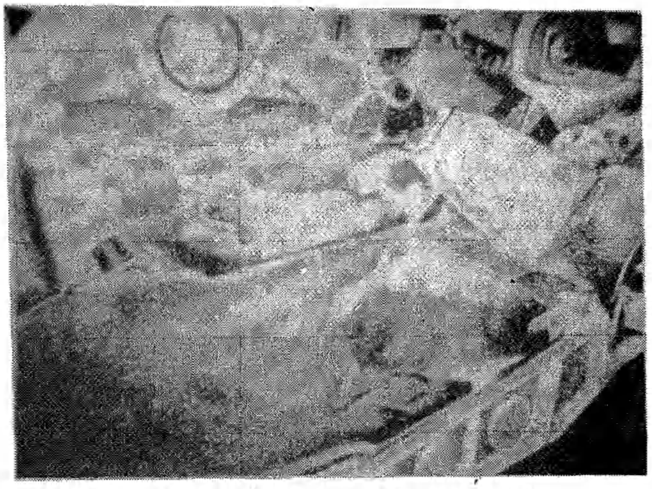
THE "VOSKHOD" PROGRAM

Sucessful implementation of the "Vostok" program opened the way for man to fly into space. A further path became clear, along which it was necessary to develop and perfect space technology, and new problems became apparent.

Multiplace spacecraft were required for performing a more extensive complex of technical operations, scientific investigations, experiments and for emergence of man from the spacecraft into open space. This task resulted from the logical development of cosmonautics. Prolonged future space flights, saturated with a very diverse and complex program of investigations, cannot be carried out by one person. Therefor, it is expedient to have a cosmonaut crew on board the spacecraft, with precise distribution of their duties. The crew may consist of an engineer, who carries out periodic inspection, and if necessary, preventive maintenance of individual systems; a scientist, who conducts scientific investigations and experiments; and a physician who is a specialist in the field of space medicine and biology. The crew may also include representatives of other specialties. The crew of the spacecraft should be headed by the most experienced cosmonaut, responsible for the entire flight program as a whole. His functions include performance of the most important operations and coordination of all crew members.

The problems of creating multiplace spacecraft and emergence of man into open space were successfully carried out during implementation of the Soviet space program for the "Voskhod""

The crews of the "Voskhod" (V.M. Komarov, K.P. Fecktistov and B.B. Yegorov) and later of the "Voskhod-2" spacecraft (A.A. Leonov and P.I. Belyayev) performed very important work on complex refinement of multiplace spacecraft and conducted extensive scientific and technical investigations.



Cabin of three-man "Voskhod" spacecraft.

The program of scientific and technical investigations, carried out by each crew member of the "Voskhod" spacecraft throughout the flight, was very heavy. The spacecraft commander, V.M. Komarov, monitored operation of the on-board systems and observed the scientific instruments, maintained manual attitude control of the spacecraft, carried on radio communications with the ground and performed a number of scientific investigations. The scientific specialist, cosmonaut K.P. Feoktistov, investigated the behavior of liquids in a state of weightlessness, conducted astronomical observations, and took still and movie pictures of the horizon and of the aureole of the earth's atmosphere. He also monitored the operation of the on-board equipment and maintained orientation and control of the spacecraft. The work program of cosmonaut-physician B.B. Yegorov naturally consisted of medical and biological experiments. He studied the complex effect of the factors of space flight on the cosmonauts, investigated their efficiency, and monitored the operation of the life-support system.

The "Voskhod" program also solved such important technical problems as creation of sufficiently comfortable conditions in the spacecraft cabin, with provision of complete pressurization, which permitted the cosmonauts to work without their space suits during the flight. The possibilities of man exercising manual control of the spacecraft during flight and during descent were determined.

The "Voskhod" spacecraft was three-man. The spacecraft weighed 5.32 tons, and consisted of a pressurized cabin and instrument compartment. The retrorockets and landing system were redundant.

The spacecraft could be controlled both automatically and manually. The spacecraft contained two orientation systems — a solar and ionic. The spacecraft could be landed both manually and automatically.

The First Man in Open Space

The main purpose of the flight of the "Voskhod-2" spacecraft was for man to walk in space. This experiment included practical tests of the main scientific and technical solutions which could ensure numerous prolonged and complex walks of cosmonauts in open space in the future for conducting planned investigations there. This was the next qualitative jump in conquest of space.

What problems were solved by Soviet designers in performing this experiment? What is the complexity of providing life support for man in open space?

On 18 March 1965, the "Voskhod-2" spacecraft, piloted by pilot-cosmonauts Pavel Ivanovich Belyayev and Aleksey Arkhipovich Leonov, went into orbit. The launch was preceded by careful ground preparation of the spacecraft under the direct supervision of Sergey Pavlovich Korolev. The cosmonauts underwent a large number of training exercises under conditions which simulated real conditions /18 to the maximum extent possible. However, there still remained questions of a purely psychological nature — what will the cosmonaut feel and how will he behave when he finds himself face-to-face with space?

Preparation for the walk began immediately after separation of the spacecraft from the launch rocket. The spacecraft commander, P. I. Belyayev, gave the command from the console for controlling the space-walk systems to open the airlock chamber. The cleverly designed airlock chamber expanded from the external side of the crew compartment, and increased several times in volume. A powerful pressurization system provided equal pressure in the airlock and spacecraft cabin. Getting up from his seat, A. A. Leonov opened the main hatch and entered the airlock chamber.

The cosmonauts performed the main operations in preparation for the walk while the spacecraft was outside the zone of radio communication with the Soviet Union. Reliable operation of the automatic systems and the confident performance of the cosmonauts ensured successful completion of these functions.

The main hatch connecting the airlock to the cabin was closed. Both cosmonauts, dressed in their space suits, again check the airlock system. The pressure in the airlock chamber gradually begins to decrease, becoming equal to that of the vacuum of space. However, the oxygen pressure in Leonov's spacesuit is maintained at 0.4 atmosphere. This ensures normal activity of the human organism, and at the same time the spacesuit under such pressure does not hinder the cosmonaut's functions too much. And this is very important, since a cosmonaut in a state of weightlessness in open space expends energy not only for movement and orientation, but in order to maintain himself near his point of support as well. And a great deal of energy is expended. For example, the force required by the cosmonaut to close his hand in the glove of the pressurized spacesuit reaches 25 kilograms.

The spacecraft is over Africa. The pressure in the airlock has finally been equalized and the outer hatch opens. The cosmos "bursts" into the airlock chamber in a stream of blinding sunlight which literally weighs on the cosmonaut. Powerful solar radiation, a considerable fraction of which is hard ultraviolet radiation, is lethal to unprotected biological organisms. The heat fluxes of solar radiation heat objects to almost 150 degrees, while at the same time the temperature on the unilluminated side drops to -140° C. Therefore, special measures were taken in designing the spacesuit to maintain a normal temperature for the human organism. The autonomous life support system also creates the necessary gas composition and humidity.

The mirror surface of the Black Sea floats by under the spacecraft. From an altitude of almost 450 kilometers, the cosmonauts can easily see the outline of its shoreline. In turn, television permits ground observation of the operations of Leonov as he emerges from the spacecraft. /19

Pushing himself away from the airlock, Leonov moves a short distance from it, and then makes the world's first independent walk in open space. He is now connected to the spacecraft only by the thin thread of the lifeline, which provides radio communications. The actions of the cosmonaut are confident — the fears of a psychological barrier were not confirmed.

The multilayer flexible covering of the spacesuit of a strong synthetic material reliably protects the cosmonaut against all unfavorable factors. Pressure at an altitude of several hundred kilometers is essentially equal to zero. Under these conditions, depressurization of the protective clothing could lead to almost instantaneous boiling of the cosmonaut's blood and his death. The cosmonaut wears a pressure helmet with special glass for observations and with a light filter to protect his eyes against the blinding effects of sunlight. Articulated connection of the elements of the space suit provides adequate freedom of movement of the cosmonaut.

Man and spacecraft are moving together at an enormous speed with respect to the Earth, covering many kilometers every second. During the period, lasting for a little more than 10 minutes during which Leonov was outside the spacecraft, the distance from the Black Sea to Sakhalin Island was covered. However, the relative motions of man and spacecraft were sensed more by the cosmonaut. The spacecraft, weighing almost 70 times more than the cosmonaut, "responded" sensitively to the maneuvering and other operations of Leonov. He even had to be especially careful not to tap too strongly on the portholes of the spacecraft. Moreover, the spacecraft began to rotate slowly due to the movements of the cosmonaut. Mounting and subsequent disassembly of the movie camera also required specific skills. All this was new, and certain details could not be foreseen on the ground.

The program for the experimental space walk was completed. According to his mission, Leonov was supposed to return to the spacecraft while on the illuminated side of the Earth. And this did not take place without surprises. The movie camera with which the space

walk had been filmed did not at all "wish" to return to the spacecraft. However, the cosmonaut returned to the airlock chamber, the hatch was closed, and the cabin was again pressurized. In the cabin, Commander P. I. Belyayev was the first to congratulate A. A. Leonov, who had spent more than 23 minutes in open space, on his remarkable victory.

The remarkable Soviet pilot-cosmonaut P. I. Belyayev played an important role in successful completion of this experiment. During /20 the flight, he controlled the spacecraft systems and equipment intended for the space walk, monitored the state of A. A. Leonov and maintained continuous communication with him, ready at any moment to go to his aid. He also controlled the reentry of the spacecraft, landing of which occurred on 19 March during the 18th orbit in the region of Perm'. Belyayev was the first to exercise manual attitude control of a spacecraft immediately prior to firing of the retrorockets. Thus ended one of the brightest pages in the history of Soviet cosmonautics.

Summing up the results of this flight, the outstanding designer of space hardware, Sergey Pavlovich Korolev, said: "The crew was assigned the most difficult, qualitatively different task compared to preceding flights. Further development of cosmonautics depended on its successful solution to the same degree as the success of the first space flight. Pavel Belyayev and Aleksey Leonov coped with it, and it is difficult to overestimate the significance of this exploit: their flight demonstrated that man can survive in open space, step out of the spacecraft without feeling restricted by its walls, and he may work anywhere necessary."

"Without this capacity, it would be impossible to think about paving new routes in space."

The results of the first space walk by man are especially apparent today in the era of the first orbital stations. The schematics for constructing the "Vostok" and later the "Voskhod" spacecraft were the basis for design and further perfection of new types and classes of spacecraft.

3. THE PROGRAM OF THE MANNED "SOYUZ" SPACECRAFT

The Tasks of the Program /21

Accomplishing systematic and purposeful conquest of space, Soviet scientists and designers have begun work on the implementation of a new space program. Whereas the "Vostok" and "Voskhod" spacecraft carried out a specific range of scientific, technical, and mainly experimental research tasks, the new manned spacecraft had a multi-purpose designation. They should have more extensive technical capabilities and solve an entire complex of new problems, designated by the space flight program. It was intended from the very beginning that such spacecraft complete a complex of investigations of circumterrestrial space and operations on assembly of orbital stations.

An Earth orbital station is the mission of today and the success of its space flight depends on the methods and means used to create it. Use of the same spacecraft for different purposes facilitates and reduces the cost of creating new space systems in orbit.

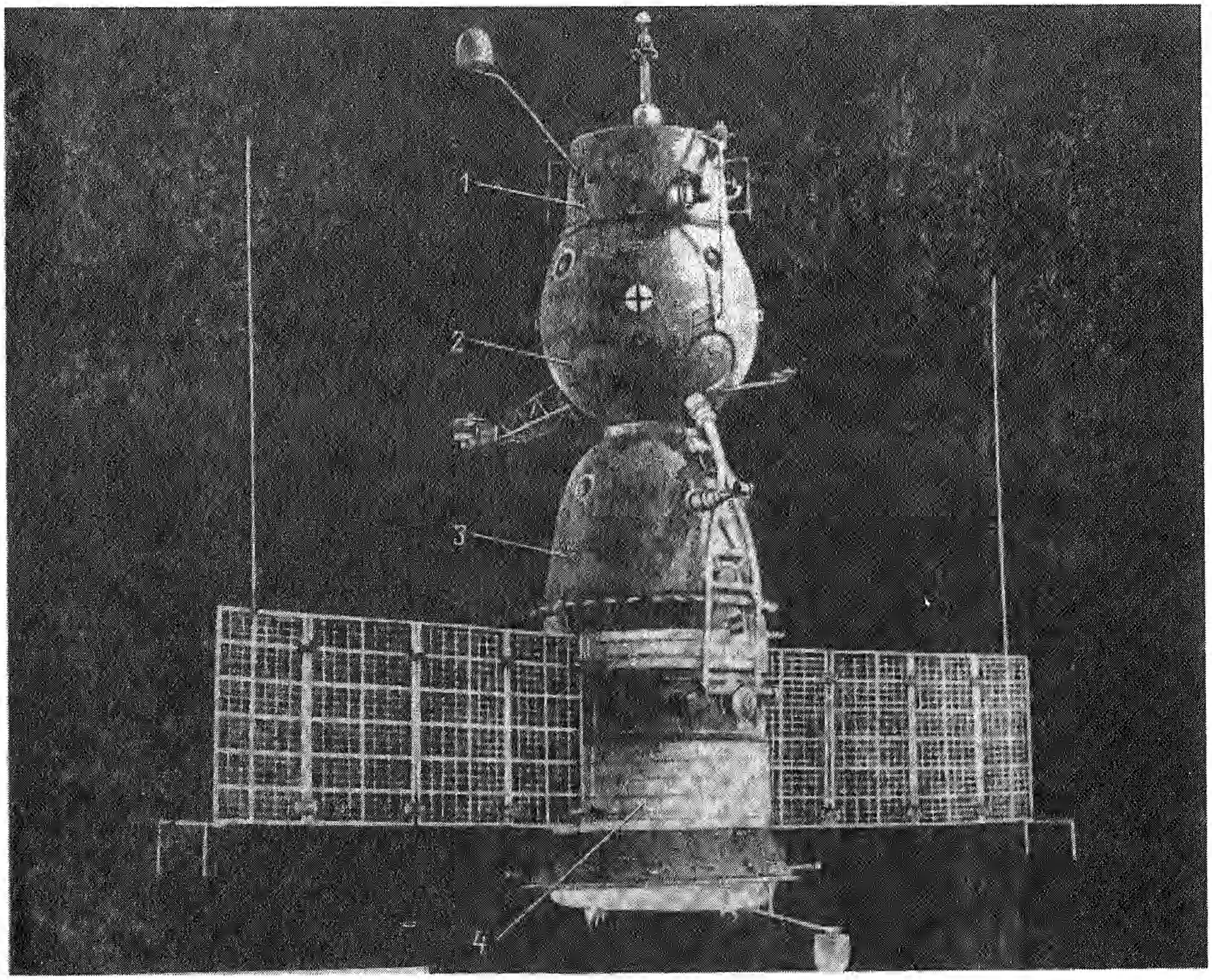
Use of the developed "baseline" spacecraft as the basis for assembly of an orbital station, organization of its supply, and investigation of space is the main problèm facing the new "Soyuz" space program.

The program also envisions prolonged study of near space. /23
Therefore, the manned "Soyuz" spacecraft are designed to solve the following specific problems:

— extensive maneuvering in group flights in Earth orbit and docking with other spacecraft;

— completion of prolonged space flights to study the effects of space factors on the human organism;

— implementation of an extensive program of scientific investigations in near space;



Model of "Soyuz" spacecraft.
1 — "active" docking units; 2 — orbital compartment; 3 — reentry capsule; 4 — instrument-equipment compartment.

— investigations of the Earth for practical purposes (weather forecasting, determination of water resources and the state of agricultural lands, observation of forest fires and the ice situation, solution of a number of problems of geodesy, geology, etc.);

— development of new navigation and spacecraft control systems.

The designers developed a special type of spacecraft, consisting of elements of both the transport spacecraft and the orbital station, to solve these problems.

Construction of the "Soyuz" spacecraft denotes a new stage in development of manned vehicles. The presence of two manned compartments — the cosmonauts' cabin (the reentry capsule) and the orbital compartment, reliable onboard systems and various types of engines for extensive maneuvering, and diverse scientific equipment permit multiple investigation, experiments, and observations in space.

Design Characteristics of the "Soyuz" Spacecraft

The "Soyuz" spacecraft consists of the following main compartments: the cosmonaut's cabin, the orbital compartment and the instrument-equipment compartment. The docking unit — an assembly intended for rigid mechanical coupling of the spacecraft and their electrical circuits — is installed in the front part of the spacecraft in the orbital compartment. Solar panels with a useful area of about 14 square meters are attached to the instrument-equipment compartment in the rear part of the spacecraft.

Antennas, attitude control sensors, television cameras and /24
sensors of the scientific apparatus are located on the outer surface of the spacecraft.

During injection into orbit, the spacecraft is protected from the effects of aerodynamic and thermal loads by a nose shroud. The solar panels and antennas are in the folded position at this time. The nose shroud is jettisoned after the spacecraft passes through the dense layers of the atmosphere.

We shall begin our description of the main compartments and assemblies of the "Soyuz" spacecraft with the cosmonauts' cabin.

The cosmonauts' cabin — the reentry capsule — is the command post of the spacecraft, as it were. The crew is in this compartment during injection into orbit, and while performing a number of operations during the flight. The crew returns to Earth in the cabin.

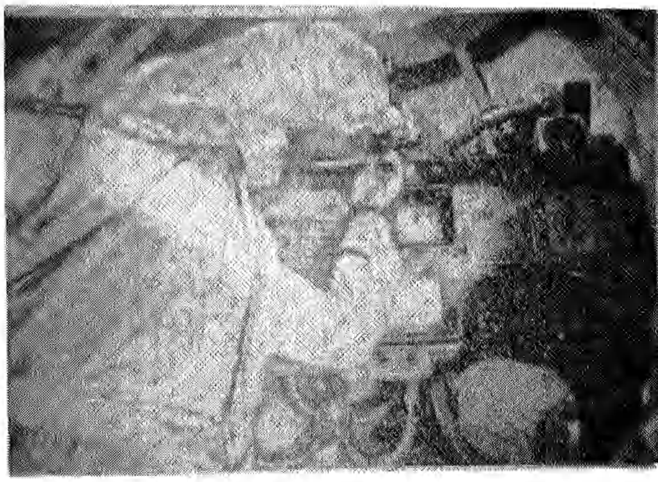
The body of the cabin is pressurized. A special heat shield is applied to its outer surface to protect against the intensive aerodynamic heat during reentry. The temperature in the spacecraft cabin does not exceed 25 - 30° C at the moment of landing due to the heat shield on the outer hull of the reentry capsule and the internal heat insulation layer.

The cosmonauts' seats are arranged inside the cabin. The posture of the cosmonauts in the seats and their position with respect to the G-forces during reentry, as well as the form-fitted seat, permit easy tolerance of even the greatest G-forces, if they occur in individual situations.

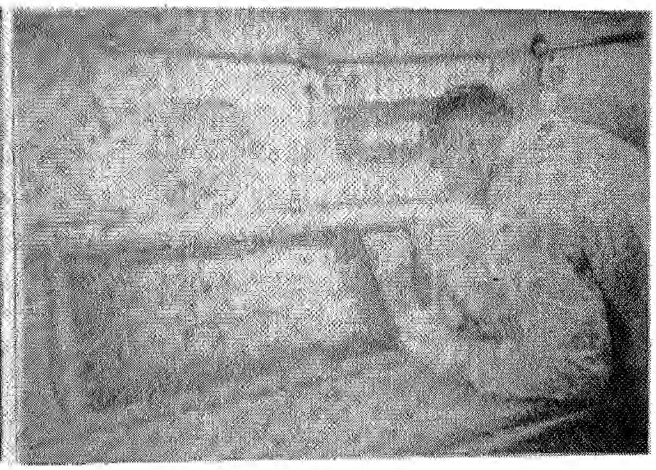
Various equipment and apparatus for spacecraft control, communication and life support systems are installed in the cosmonauts' cabin. The main and reserve parachute systems are located in special containers. The spacecraft commander is located in the center seat. The spacecraft control console, on which are mounted the instruments for monitoring the operation of systems and assemblies, navigation equipment, a television screen and switches for controlling the onboard systems are installed directly in front of him. Lateral auxiliary consoles, for example, the console for medical monitoring of the state of the cosmonauts during operations in open space, are arranged alongside the center console. An optical sighting device — a navigation device — is installed in a special porthole.

There are two spacecraft control levers along the sides of the commander's seat: the right one is for attitude control of the spacecraft around the center of mass, and the left one is for changing the speed of the spacecraft during maneuvering. The cabin contains two portholes for visual observation, and for taking still and movie pictures.

The spacecraft equipment provides for independent piloting of the spacecraft without participation of the ground control complex.



Assembly of equipment in reentry capsule.



Assembly of equipment in orbital compartment.

With the aid of heat regulating and regenerative systems, the spacecraft cabin is provided with normal conditions for functioning of the cosmonaut (pressure, gas composition, temperature and humidity). /25 During flight, the crew may wear normal clothing without spacesuits. Containers with food and water supplies are located in the cabin.

The outer enclosure of the cosmonauts' cabin (the reentry capsule) has a special shape resembling a headlight — a segmented body. This shape of the reentry capsule with the appropriate location of the center of gravity provides a certain aerodynamic lift during flight in the atmosphere. The hull of the reentry capsule contains jet engines for controlling banking turns during reentry and solid fuel rocket engines for soft landing.

The extent and direction of lifting force, by which is achieved control of the descent trajectory, is changed by turning the reentry capsule in a banking angle. A reentry trajectory using lifting force is much longer in duration, and, accordingly, reentry along it occurs at lower G-forces than that along a ballistic trajectory.

The cosmonauts' cabin is connected to the orbital compartment — the second living compartment of the "Soyuz" spacecraft — by means of a pressurized hatch.

The orbital compartment is designed for scientific observations and investigations, for emergence into space, and also for the cosmonauts to rest. It is almost spherical in shape and has rather large dimensions. The compartment is equipped with places for the cosmonauts to work, rest and sleep. /26

Control and communication equipment, a portable television camera, movie and photographic apparatus and scientific instruments are located at the work sites. The cosmonauts record the results of their observations in a logbook or on a dictaphone.

Besides the special communication equipment, the orbital compartment contains an all-wave radio receiver for listening to programs of ground-based radio stations. There are special cupboards for stowing the life support equipment, food supplies, scientific apparatus, medicines and hygiene articles.

The orbital compartment may be used as an airlock chamber for space walks. For this it is equipped with a special locking system which ensures exhaustion of gases and pressurization of the compartment. Exit is accomplished through a hatch which is opened either automatically or manually.

The instrument-equipment compartment, designed for accommodation of the main onboard equipment and the spacecraft engines operating during orbital flight, is adjacent to the cosmonauts' cabin. The apparatus and equipment are located in a pressurized instrument compartment, inside which conditions are maintained which are necessary for normal functioning of them. The heat regulating and power supply systems, radio communication and radio telemetry equipment, and instruments for the attitude control systems using computers are concentrated in this compartment.

The instrument-equipment compartment contains a liquid jet engine which is used for maneuvering in orbit and also for reentry of the spacecraft. It has two engines with 400 kilograms thrust each. The

capacity of the engines is such that the "Soyuz" spacecraft can complete maneuvers to an altitude of 1300 kilometers.

There is an engine system with less thrust for attitude control, and for translation of the spacecraft during maneuvering.

The Main Systems of the "Soyuz" Spacecraft

One of the main systems of the "Soyuz" spacecraft is the attitude and motion control system. It provides attitude control of the spacecraft in space, its stabilization through operation of the engines, and control of the spacecraft during approach, mooring and docking of spacecraft both automatically and manually.

The attitude and motion control system includes:

attitude sensors and the cosmonaut's optical sighting device; /28

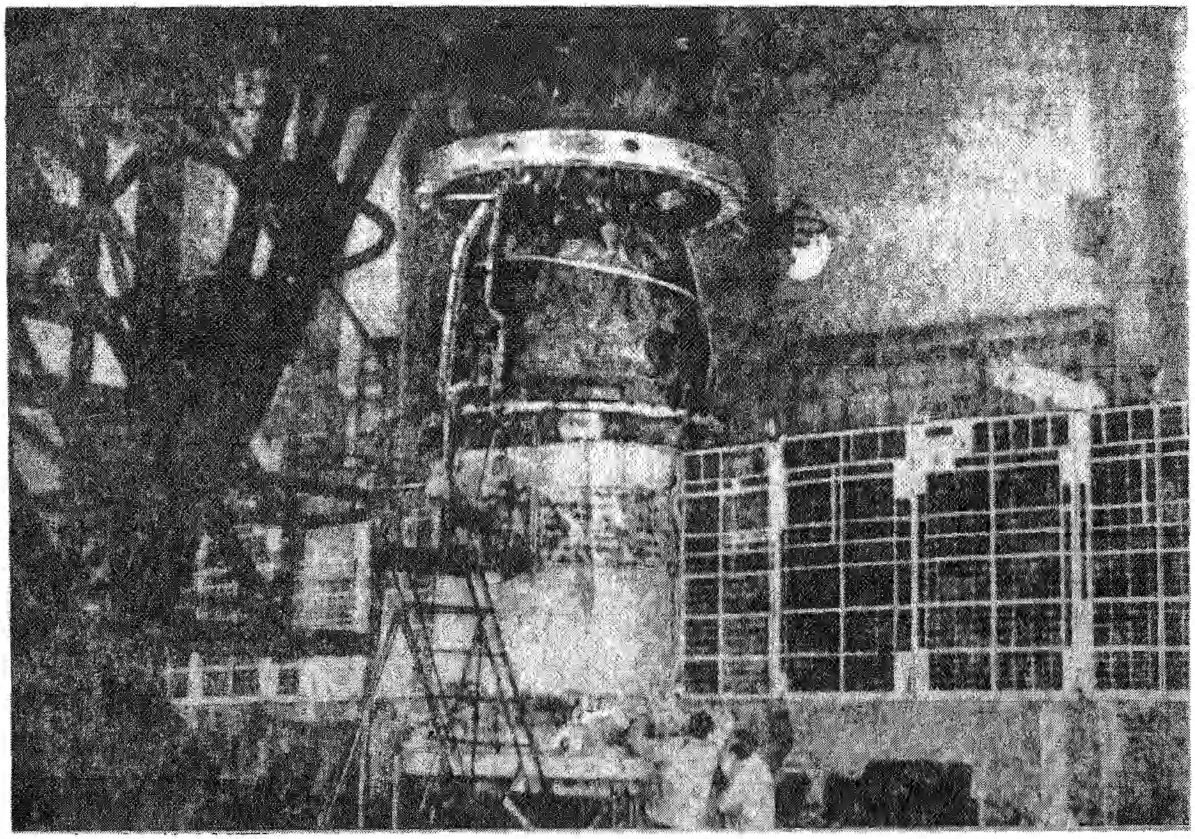
gyroscopes and electronic computer control circuits;

radio aids for search and homing;

a system of auxiliary control members — low-thrust engines.

The power supply for the onboard equipment and apparatus is provided by a centralized electric power system. The spacecraft buffer batteries are charged by the solar batteries. In order that the solar batteries be continuously illuminated, they are oriented toward the sun and maintained in this position by turning the spacecraft with respect to this direction at a speed of several degrees per second.

The radio aids of the "Soyuz" spacecraft provide reception of commands from the ground, two-way radio telephone and telegraph communications, calculation of orbital parameters, transmission to Earth of television images of the internal and external situation of the spacecraft. During the flights of the "Soyuz" spacecraft, there were several television reports from the craft directly to the ground television network.

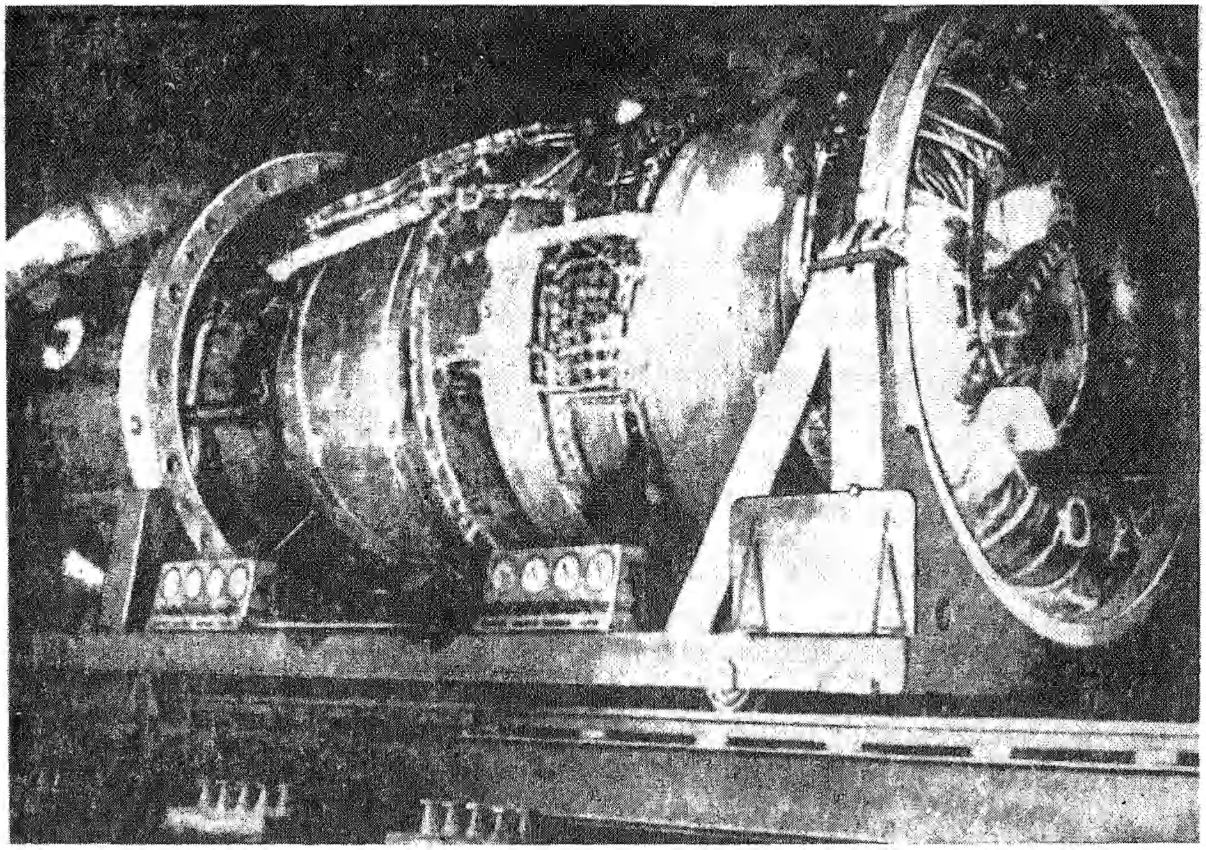


Overall assembly of "Soyuz" spacecraft.

The multichannel radio telemetric system provides transmission of a large volume of data. When the spacecraft was flying beyond the visibility of ground receiving stations, the telemetry data were stored in the onboard memory devices and transmitted to Earth during the routine radio communication schedules.

The "Soyuz" spacecraft are equipped with a docking system. This system was checked twice during the flights of the "Kosmos" satellites and during the flight of the "Soyuz-4" and "Soyuz-5" spacecraft, and displayed high operational reliability.

The normal hygiene-physiological conditions for the spacecraft crew are provided by the life support system. The atmospheric regenerative system maintains a gaseous composition in the compartments, similar to that on the ground.



Transportation of spacecraft for final tests.

The heat regulating system maintains normal temperature and humidity in the compartments, the level of which may be regulated as the cosmonauts wish. The flights of the "Soyuz" spacecraft demonstrated reliable operation of all onboard systems, providing efficient performance of complex scientific and technical experiments in space. The comfortable conditions in the living compartments of the spacecraft and the ease of control, work and rest throughout the entire flight contribute to retention of high efficiency of the cosmonauts and successful completion of the assigned program.

These are the main features of the "Soyuz" spacecraft.

Compared to the "Vostok" and "Voskhod" manned spacecraft, the following important technical problems were more completely resolved here:

the cosmonauts were provided with more living space for work and rest — two living compartments: the orbital compartment and the cosmonauts' cabin;

reliable docking and assembly were accomplished (with the aid of automatic systems and manually);

extensive maneuvers were carried out in orbit and during controlled reentry;

prolonged space flights were carried out.

Fabrication and Ground Testing of the Spacecraft

Fabrication of the Spacecraft

While the "Voskhod" spacecraft were still flying in space, design and fabrication of the "Soyuz" spacecraft — the basis of orbital space stations and multipurpose manned spacecraft — were underway in design offices, laboratories and plants.

Fabrication of a spacecraft is a long and complex process. Not only must its structural elements, compartments and assemblies be fabricated, but its systems and different equipment must be developed and tested.

We are in the workshop for assembly of the reentry capsule. There are several production lines here. In order to expand the area of operations and for ease in assembly, the reentry capsule is "divided" into two parts: a lower part — the bottom — and an upper part or "bell".

The supporting frame is assembled in the bottom. The instruments installed in the lower part of the reentry capsule are attached to the supporting frame and to the body of the bottom; the supporting frame of the cosmonauts' seats is attached above the instruments. Assembly proceeds according to a precisely planned interchangeable diagram — each operation is carried out in turn.

The brackets for attaching the instruments are also being

assembled in the body of the reentry capsule bell, the instruments themselves are then installed. The electric cable is laid out and the cosmonauts' console is assembled.

The remaining units and assemblies are assembled simultaneously. And now everything is ready. The primary units, assemblies systems and entire compartments first leave the assembly shop for tests. And only after they have been tested (for strength, vibration, high pressure, vacuum, etc.) according to the required specifications may they be installed in the spacecraft.

Thermal models of the spacecraft are tested in a high-vacuum pressure chamber. The efficiency of the mechanical systems for deploying the antennas and solar batteries is checked and the compartments and assemblies are tested for air-tightness.

The heat shield of the hull of the cosmonauts' cabin is tested in a special "space oven" under the effects of ultrahigh temperatures, which may occur during reentry.

The compartments of the spacecraft are subjected to tests on all the test benches possible in the strength laboratories. The vibration resistance of the compartments and of the spacecraft as a whole is /31
tested. The spacecraft and all its members should tolerate vibrations which occur during the main stages of the flight.

The reliability and efficiency of the spacecraft structure are checked on the dynamic strength test benches: after all, the spacecraft may be subjected to high G-forces during flight.

The structure and equipment of the reentry capsule are tested in impact strength laboratories. Possible landing conditions — on rocks, ground, snow, ice, swamp and water — are simulated.

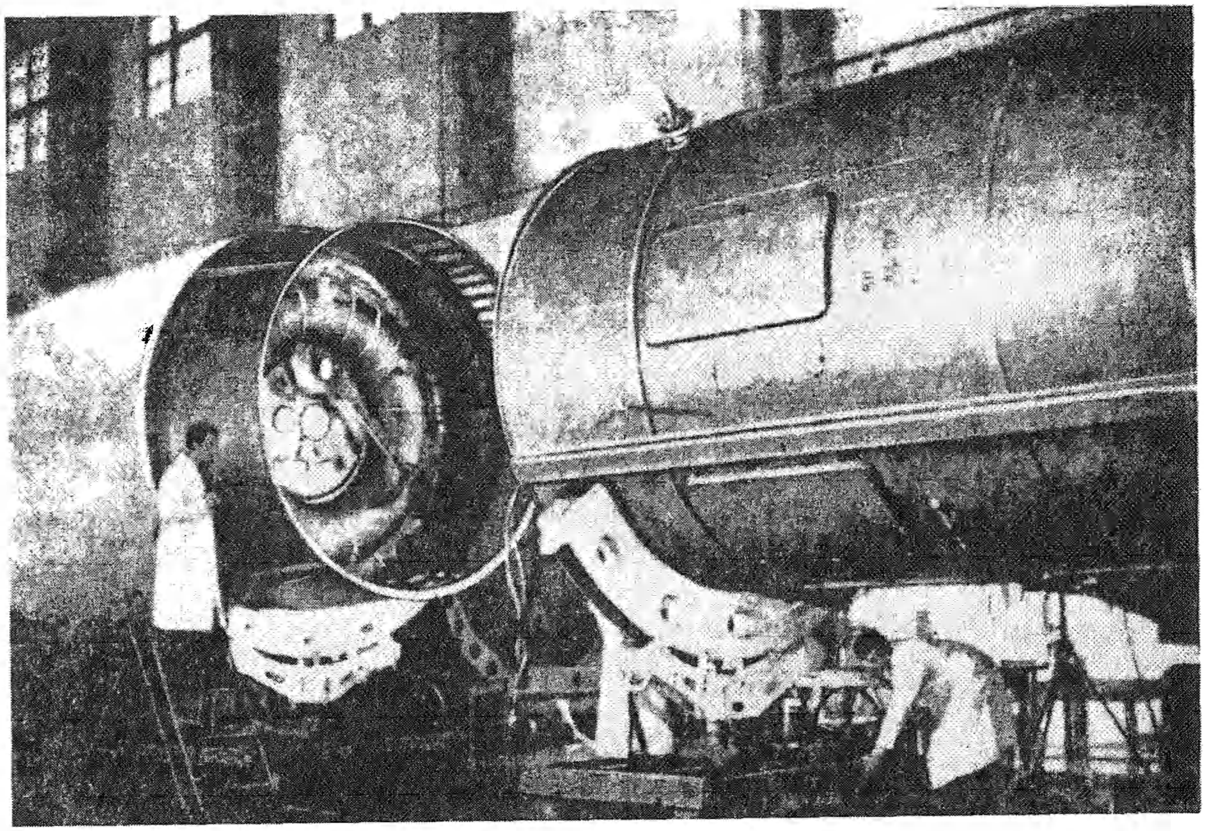
Ground Testing of Systems

Nose cone separation. Thus, the spacecraft has been fabricated at the factory and has been tested. Operation of its systems under conditions similar to flight conditions must now be tested.

The spacecraft is mounted on the launch rocket under a special nose cone with emergency escape rockets. The nose cone is used to protect the spacecraft from the effects of the high dynamic pressure of the atmosphere and high thermalloads which occur during injection into orbit. The launch rocket and spacecraft passes through the atmosphere at high speed, which heats the body of the rocket to high temperatures. The nose cone is supposed to open and separate from the rocket after passing through the zone of maximum thermal and dynamic loads. It is no longer needed. The success of the rest of the flight depends on how the nose cone was jettisoned.

The correctness of the theroetical calculations on the process of jettisoning the nose cone is verified by special experiments. A model of the spacecraft with folded antennas, solar battery panels and operating nose cone and its systems is mounted on the test bench. The cone is repeatedly shot off. The entire process is photographed by high-speed movie cameras and telemetric sensors record the operational parameters of the systems. As a result of the experiments the actual trajectory of the cone elements with respect to the spacecraft and the rocket stage, as well as the speed of separation of the leaves, are calculated. Operation of the thruster explosive systems is evaluated and if necessary the size of the powder charges and force of the thruster springs are altered.

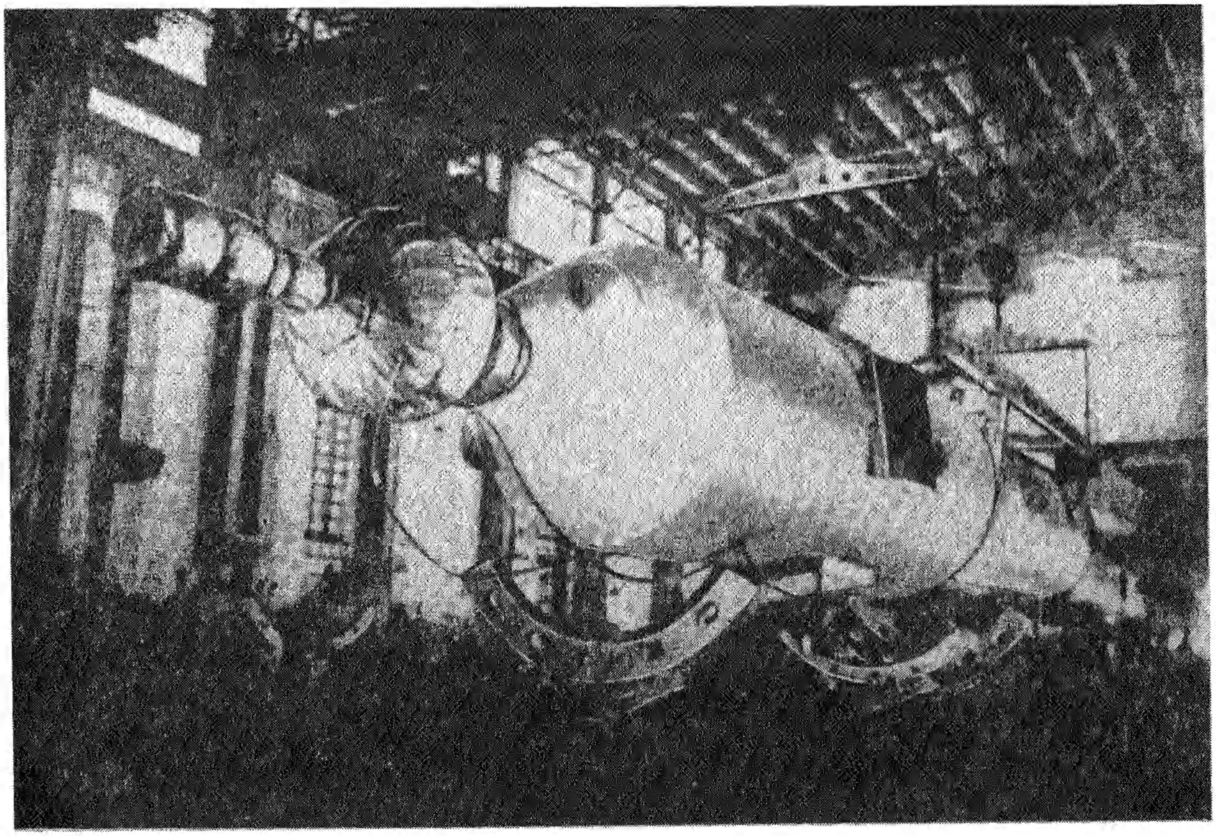
Reentry capsule separation. The reentry capsule may separate from the spacecraft in two cases: during operation of the emergency escape system, and during reentry. The reentry capsule and the adjoining portion of the spacecraft compartment with its separation systems are mounted on the test bench. A more suitable speed of separation of the compartments is selected due to a change in the firing rate of the reentry capsule. Emergency situations which may occur at the moment of separation of the compartments are reproduced. In all cases, the reentry capsule should separate at the proper moment.



Joining of the nose shroud and "Soyuz" spacecraft to launch rocket.

Deployment of the antennas and solar batteries. The spacecraft /34
cannot be injected into orbit in the form in which it flies in space, since the effective air flow during the active leg has enormous dynamic pressure and creates considerable thermal loads. Therefore, all protruding parts of the spacecraft — the antennas and solar batteries — must be folded and covered with the nose cone. This complicates the construction and operation of the spacecraft systems. After injection into orbit, the antennas of the radio system are deployed and occupy their operating position, and the solar batteries also unfold their panels several meters in length.

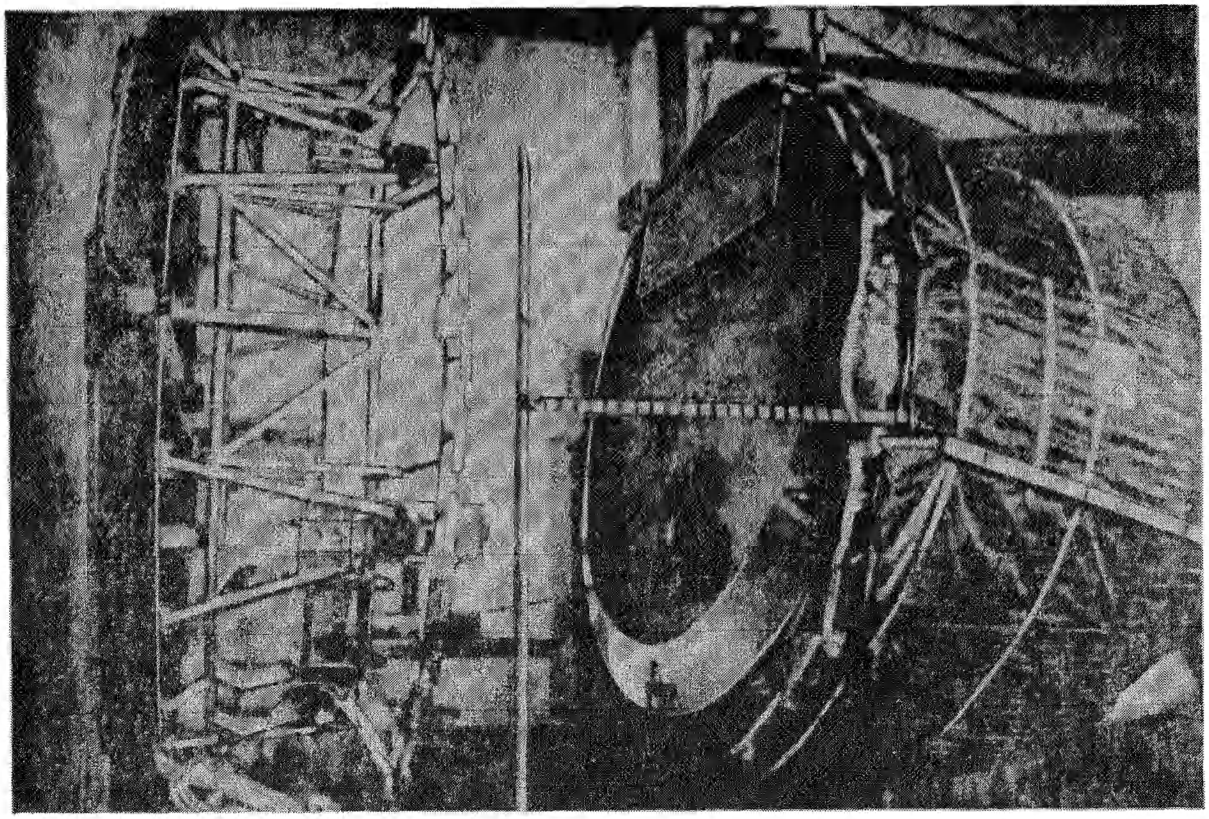
Operation of all systems and circuits which participate in deployment of the antennas and solar battery panels is carefully worked out on the ground. Operation of the mechanical assemblies and deployment of the antenna systems is checked in high-vacuum pressure chambers.



Transporting launch rocket from assembly shop.

All members lose weight in space, which means that this must be taken into account during ground tests. A model of the spacecraft with actually operating antennas and solar batteries is mounted on the test bench. In order to eliminate the effects of weight, long wires, several meters long, which are fastened to the ceiling of the laboratory, are attached to the folded antennas.

The weight of the antennas is neutralized by the tension of the wires to simulate weightlessness. The solar batteries under the cone are folded in a package around the hull of the spacecraft. During ground testing of their deployment, they rest on roller supports which move freely along a level surface. The command is given for deployment. The explosive bolts and pins are actuated. The antenna sections and solar battery panels unfold in sequence in response to the springs. Appropriate sensors record the deployment

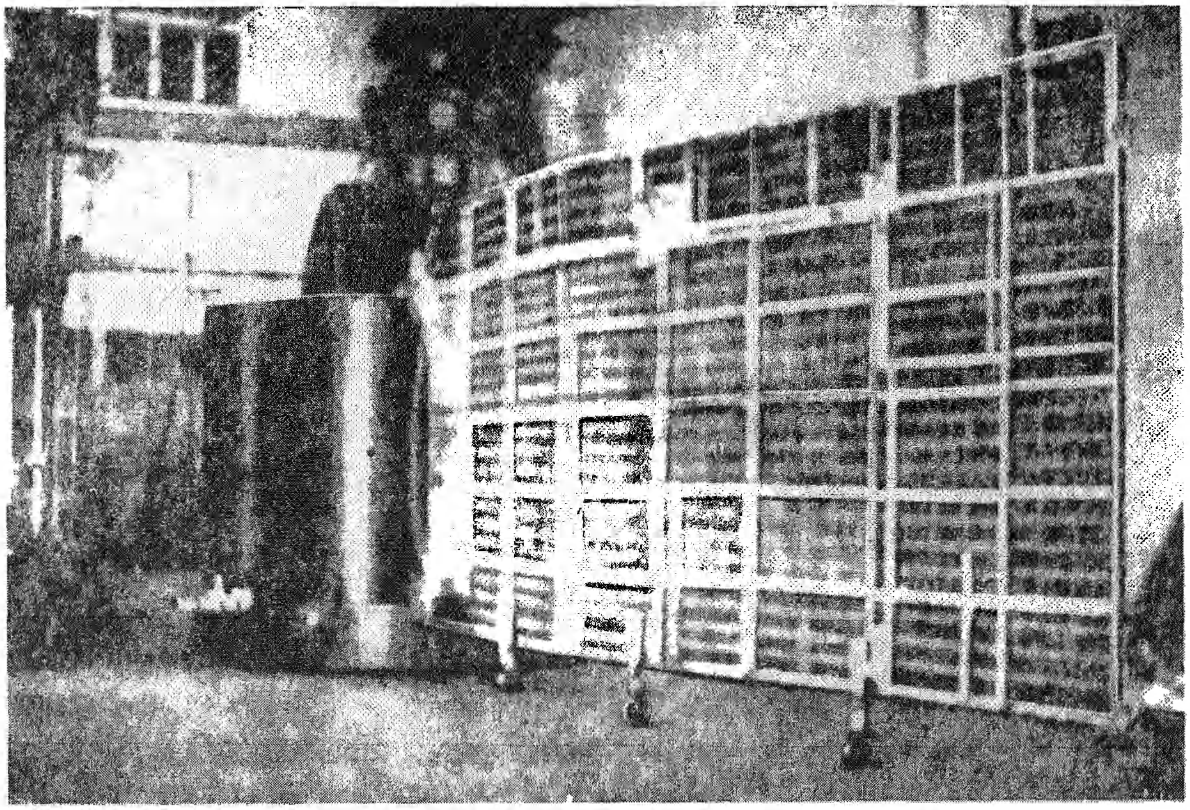


Testing separation of reentry capsule.

forces and those acting on the antennas and panels. Reliable and impactless methods of deployment and securing of the antennas and batteries are selected.

Flight Tests of the Spacecraft Systems

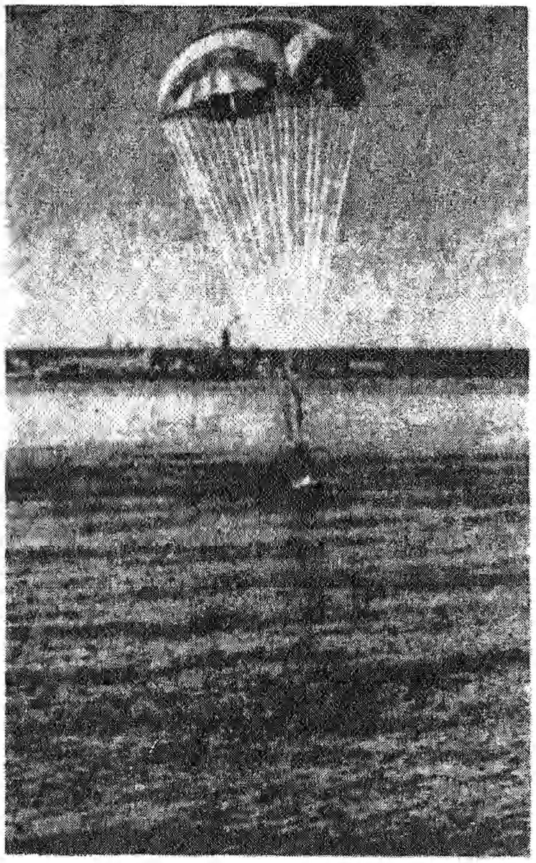
Conditions similar to those during an actual space flight may be created experimentally for certain stages of the spacecraft flight. This refers mainly to the stages of flight through the dense layers of the atmosphere: reentry of the recovery capsule and controlled descent, operation of the emergency escape system, parachute descent in the atmosphere and soft landing.



Testing solar battery and antenna deployment system.

Testing the heat shield of the reentry capsule and the controlled descent system. The heat shield, aerodynamics, and control system of the reentry capsule are tested under conditions close to calculated, with the aid of geophysical rockets. A model of the reentry capsule with its heat shield and controlled descent systems is lifted by a geophysical rocket beyond the dense layers of the atmosphere. The model is separated and makes a controlled descent under conditions close to real.

Telemetric sensors, which record temperature, ablation of the heat shield and operation of the various systems during reentry are installed on and inside the heat shield of the model. The aerodynamic and ballistic characteristics of the reentry capsule, effective G-forces during reentry, and dynamic and thermal flows are refined as a result of flight tests of the model. /3'



Testing parachute system.

<u>Testing the landing systems</u>. The parachute system and soft landing engines are tested by dropping the reentry capsule from an aircraft. All conditions for deployment of the parachute system — flight speed of the reentry capsule (about 200 meters per second), profile of the descent trajectory and spatial orientation of the reentry capsule — are maintained during the drop.

The permissible angles of incidence of the reentry capsule at the moment of deployment of the parachute system and maximum dynamic pressures acting on the parachute during deployment are calculated during the tests. The strength characteristics and efficiency of the various structural elements of the parachute systems and firing systems of the hatches, covers, etc., are investigated.

When the aircraft reaches the required altitude and speed, the reentry capsule separates from it, and then flies independently and stabilizes itself until the parachute system deploys at an altitude of 10 kilometers. Further descent takes place by parachute. The /38
dynamics of deployment of the drogue and main parachutes is calculated during the tests.

Movie cameras installed in the arcraft take pictures of the parachutes emerging from the parachute container, their deployment, and operation during descent.

Landing of the reentry capsule is tested on snow, dry land, water, and rocky surfaces.

Investigating the stability of the reentry capsule during water landing. Sea tests are carried out to determine the actual buoyancy of the reentry capsule (such an event is not excluded). For this, the reentry capsule is dropped into the water. The crew is inside the capsule, and all systems required for man to live and function are installed.

The cosmonauts test methods of leaving the capsule, remaining on the surface of the water, and evacuation with the aid of helicopters and ships.

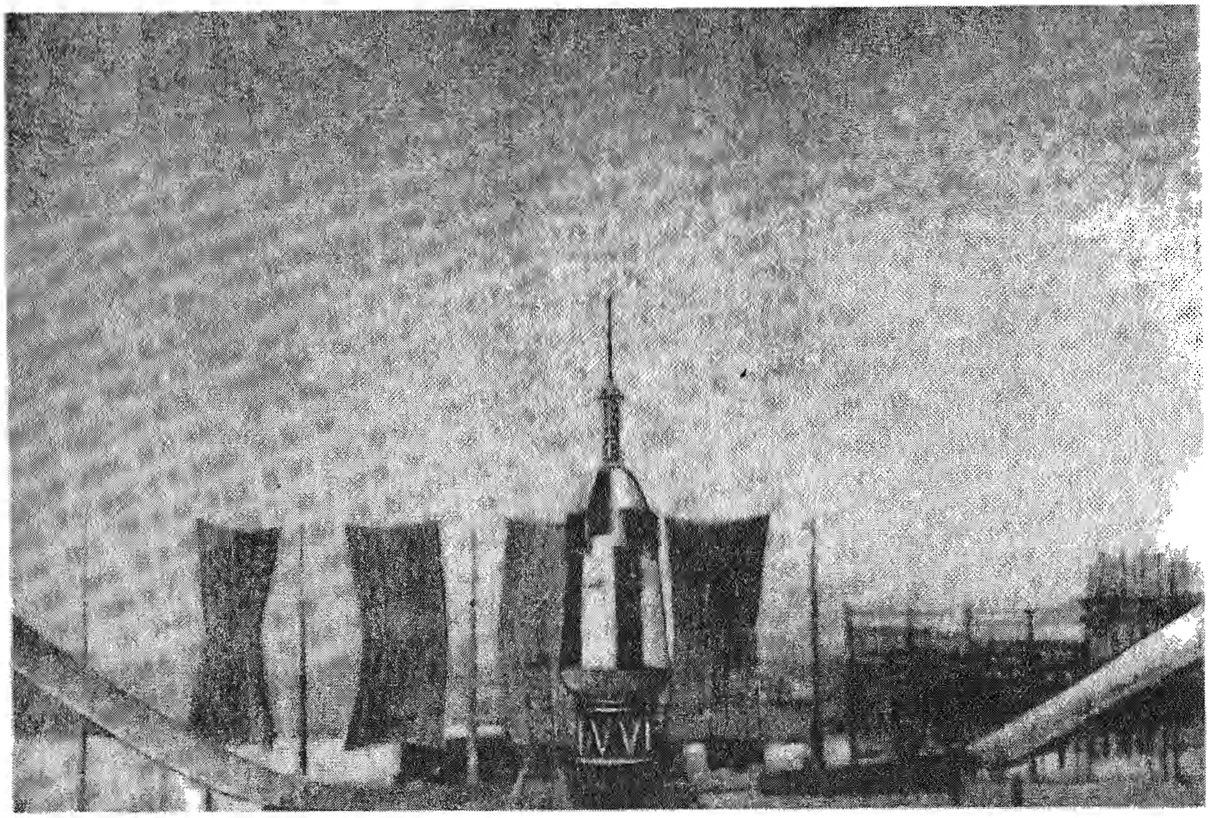
Testing the emergency escape system. The cosmonauts are in the cabin during launch and orbit injection of the "Soyuz" spacecraft. Therefore, special solid-fuel rocket engines, which separate the cosmonauts' cabin and nose cone and carry it away from the launch rocket during dangerous flight situations during the active phase of the trajectory, are installed on the nose cone of the "Soyuz" spacecraft. The cabin then separates from the spacecraft, emerges from the nose cone and makes a parachute descent and soft landing.

The emergency escape system must be highly reliable.

The final test of the emergency escape system takes place during flight testing. For this the most diverse flight emergencies such as deviation of the rocket from the flight trajectory, engine failure, uncalculated G-forces, fires, explosions, etc., are created during the tests.

Telemetric sensors record the operation of systems during the tests, all characteristics of systems operation are analyzed, and only after this is the reliability of the emergency escape system confirmed and recommendation made that it be installed on the spacecraft.

Thus, the spacecraft has been designed, fabricated and tested and is ready for flight. The launch and command control complexes are ready.



Testing the emergency escape system.

And the tests are still continued, but now during actual space flight. Unmanned versions of the new spacecraft are first launched into space. Its flight program is extensive and operation of all systems and assemblies of the spacecraft must be tested and checked all together. And cosmonauts fly into space only after careful testing of the spacecraft during orbital flights in automatic versions and after its reliability is confirmed.

Training the Cosmonauts for Space Flights /40

Cosmonaut selection procedures and the training program are developed on the basis of careful analysis of the results of investigating the effects of space flight factors on the organism.

Rocket engines of emergency escape system.

The first group of cosmonauts was recruited from among pilots. The future cosmonauts were subjected to rigorous medical examinations. The capabilities of the main physiological systems of the body were investigated in a pressure chamber at significant levels of atmospheric rarefaction, during drops of barometric pressure, as well as in centrifuges, on vibration tables, etc.

The cosmonaut candidates were also subjected to psychological examination to select personnel having the best memory, alertness, and ability for rapid and precise coordinated movements.

A group, which began a special training program, was formed as a result of medical and physiological examination. The training program was made up of a complex of special tests and training exercises, various types of general physical conditioning, and also special theoretical study courses.

The special training program was designed for the cosmonauts to acquire the necessary information about the basic theoretical problems /41 related to the flight missions, as well as practical skills in use of the equipment and apparatus of the spacecraft. The program provided study of rocket and space technology, spacecraft design, special problems of astronomy, geophysics and the fundaments of space medicine.

The complex of special training exercises and tests included:

aircraft flights under conditions of weightlessness;

training exercises in a model of the spacecraft cabin in a special simulator;

prolonged restriction in a specially equipped soundproof chamber;

training exercises on a centrifuge;

parachute jumps from aircraft.

The flights of the Soviet cosmonauts confirmed the correctness of the principles applied to the system for selection and training of cosmonauts.

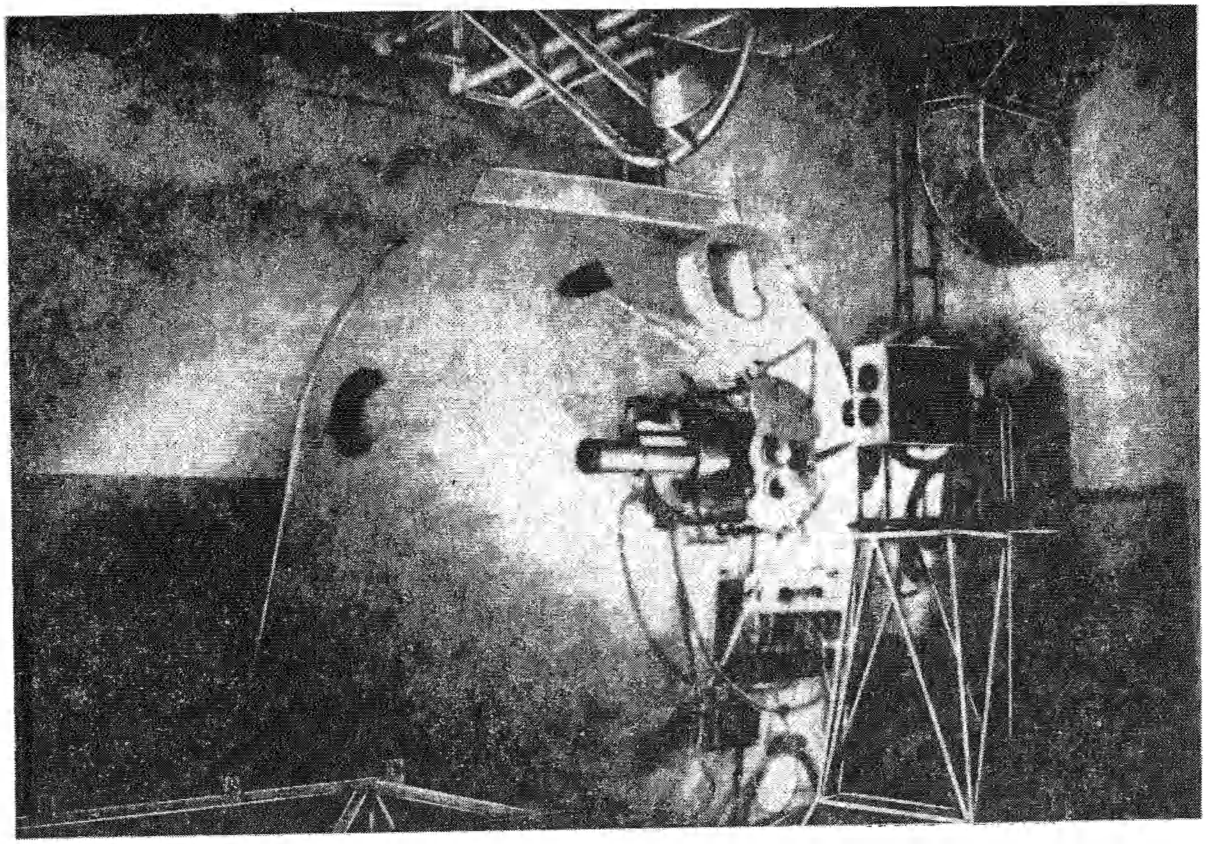
The cosmonaut training program consisted of two stages: the first stage included study of the spacecraft during its creation in the design office and the second stage included direct flight training. The cosmonauts participated in solution of the problems related to experimental development of the compartment configuration and tests of the manual control systems.

Participation in ground tests of the spacecraft and its systems was good preparation of the cosmonauts for future space flights.

During the second phase of training the cosmonauts developed skills in special simulators in control of the spacecraft systems and in performing specific operations envisioned by the preflight program.

Maximum simulation of all actual conditions was created in the various simulators.

The cosmonauts had at their disposal a multiple simulator, special simulators as well as flying laboratories and pressure chambers. The multiple simulator was designed for developing the cosmonauts' skills in performing the various missions of space flight. A simulator is a full-scale electrically operated model of the spacecraft compartments, with simulation of the various characteristics of space flight, the internal configuration of the equipment and the external situation



Reentry capsule-simulator.

visible from the spacecraft. The cosmonauts spent many hours in "flights" in the multiple simulator. During training exercises in the multiple simulator, the cosmonauts worked out the finishing touches for the flight program and flight mission and "performed" scientific investigations and experiments.

Simultaneously with training exercises in the multiple simulator, exercises were carried out in the specialized and functional simulators, which more accurately simulate the dynamics of spacecraft motion during manual control. The more important individual operations on manual orientation, manual mooring and docking were developed in these simulators. /43

Testing exit from reentry capsule at sea.

Training exercises in full-scale models with standard systems installed in pressure chambers, where the cosmonauts worked with the airlock chamber, spacesuits and autonomous life support systems in a high vacuum, i.e., under conditions simulating those of space flight, occupied an important place in flight training.

Along with training exercises in ground simulators, flights were carried out in flying laboratories, where all elements, related to transfer of cosmonauts from one spacecraft to another, were tested under conditions of brief periods of weightlessness.

Training exercises with G-forces, which develop during orbit injection and controlled reentry, were carried out in special centrifuges, which reproduced actual G-forces during these phases of the flight.

Besides these types of professional training (including physical and medical-biological), the cosmonauts carried out special flight and parachute training.

Both aircraft flights and parachute jumps are an important part of cosmonaut training. High-altitude flights in fighter aircraft familiarized the cosmonauts with the external situation similar to that of space flight. Aircraft flights permitted the cosmonauts to prepare for work under conditions of variable G-forces and brief periods of weightlessness, to condition the vestibular apparatus and to develop skills in spatial orientation.

Flights in a closed cockpit and in clouds enhaced development of skills of distribution of attention on the instruments. En route flights permitted them to develop visual orientation by ground reference points. Celestial navigation was mastered and skills in star orientation and performance of astronomical measurements and observations were developed during flights in a specially equipped flying astronomical laboratory.

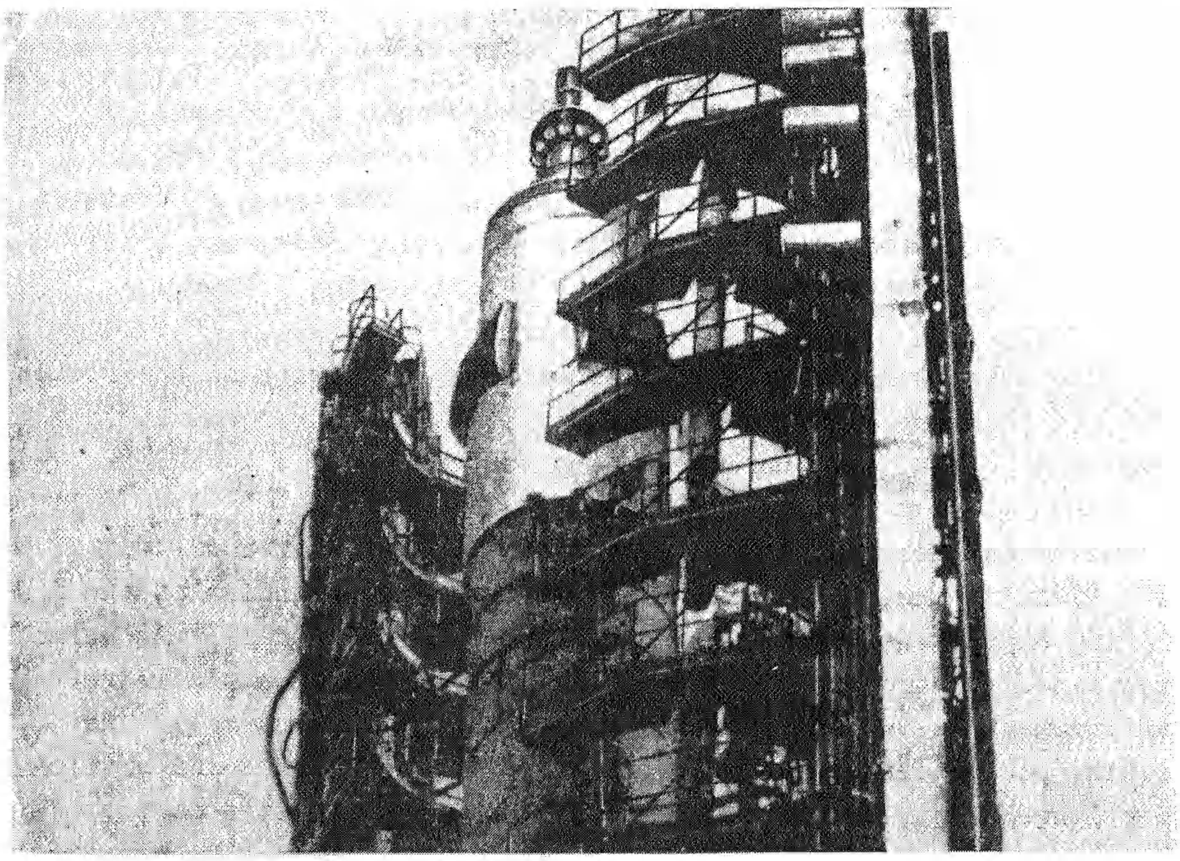
4. THE MAIN STAGES OF FLIGHT OF THE "SOYUZ" SPACECRAFT

Orbit Injection /44

"Soyuz" type spacecraft are injected into orbits of artificial Earth satellites by powerful multistage launch rockets. The ground launch complex of the Baykonur Cosmodrome provides preparation and launch of spacecraft at any time of year. Thus, the launch crews during launching of the "Soyuz-4" and "Soyuz-5" spacecraft, despite the severe conditions of the Kazakhstan winter, carried out pre-launch operations carefully and on schedule.

The huge body of the rocket, surrounded by service towers and umbilicals, is covered by light clouds of fuel vapors. Last-minute preparations are being carried out. Approximately two hours prior to launch the spacecraft crew rides the elevator to the top section of the rocket and enters the orbital compartment through the entrance hatch. After inspecting the equipment for the second time, the cosmonauts descend through the transfer hatch to the crew compartment. Both hatches are then hermetically sealed.

The cosmonauts carefully inspect the numerous instruments and indicators, switch on the various buttons and keys on the console, located directly in front of them, in order to check them. During those several tens of minutes remaining prior to launch, they check the signalling devices and initial state of the systems.



Launch rocket in umbilicals.

Check-out is now completed and everything is in order. The rocket is ready for launch. The cosmonauts strap themselves into their seats with the aid of restraining harnesses. /46

All control over the complex systems of the spacecraft and rocket is now exercised by the ground crews and automatically.

The launch pad is empty. All members of the launch crew are in the command and observation posts. The umbilicals and cable tower move away from the rocket body one after the other. One hears the pre-launch commands for resetting the various systems and, finally, "Ignition! Launch!"

A blinding flame bursts forth from underneath the rocket. A deafening roar is heard. This is the rocket engines igniting. However, the rocket remains immobile. The hold-down arms restrain it until the engines reach their calculated operating mode, and until the developed thrust exceeds the launch weight of the rocket.

After several seconds the hold-down arms fall away and the rocket begins its headlong acceleration into the reaches of space. It is very slow at first, but then faster and faster.

The cosmonauts are pressed against the backs of their seats. Like a living thing, the rocket body vibrates and the noise of the operating engines is heard. The cosmonaut reports: "Flight is normal. I feel fine. G-force 2.5." This means that the cosmonaut's weight at this moment is two and one-half times greater than normal. The operating parameters of the spacecraft and rocket systems and a television image of the cosmonaut are continuously transmitted to the ground command and control complex. Orbit injection is the primary responsible stage of space flight.

At the beginning of the active phase the rocket rises at a rather steep angle in order to pass through the dense layers of the atmosphere along the shortest route. During this period the spacecraft, being in the front section of the launch rocket, is covered by the cone. The cone is jettisoned at a specific time beyond the dense layers of the atmosphere.

The automatic control system of the launch rocket determines the operating mode of the engines, provides motion stability and carries out staging throughout the entire period of the active leg of the flight. The control systems force the rocket to deviate more and more from a vertical position as flight altitude increases. Speed toward the end of operation of the last stage engine should be not only almost 8 kilometers per second, but should also be directed so that the spacecraft continues to move in the orbit of an artificial Earth satellite. Weightlessness begins in the spacecraft after the engines are cut off and it separates from the last stage of the launch rocket.

Orbital Flight

The spacecraft is now in orbit! The solar battery panels and antennas of the onboard radio aids deploy upon command from the programming-timing unit.

The spacecraft is rotating slowly due to the perturbations induced during separation from the last stage of the launch rocket. Therefore, one of the main systems of the spacecraft — the attitude control system — is switched on immediately.

Reliable radio communication is maintained with the cosmonaut. Telemetry data about the state of the onboard systems and assemblies of the spacecraft are transmitted to the ground monitoring stations. The spacecraft now "leaves" the territory of the Soviet Union and continues its flight above the reaches of the Pacific Ocean. However, communication with the spacecraft continues for some time via the scientific research ships of the Academy of Sciences, which are out at sea.

Gyroscopic Orientation ("Warping") of the Spacecraft toward the Sun

The time and place approach for implementing a routine operation called "warping the spacecraft toward the Sun."

The cosmonaut presses a key with the inscription "Warping." Upon this command, the low-thrust engines on the spacecraft hull are switched on, ensuring that it rotates around one of the axes. Images of the Earth, stars, Moon and Sun float by on the screen of the optical sighting device.

The cosmonaut makes a slight motion with the control knob and the Sun begins to "describe a circle" within the field of vision of the optical sighting device. Another motion and the cross-hairs merge with the image of the Sun.

In this position the spacecraft is oriented such that the spacecraft — Sun axis is perpendicular to the surface of the solar battery panels. And this means that the maximum luminous flux will impinge on them and, consequently, that the greatest electric current develops. The electrical energy taken from the solar battery surface will now charge the spacecraft storage batteries.

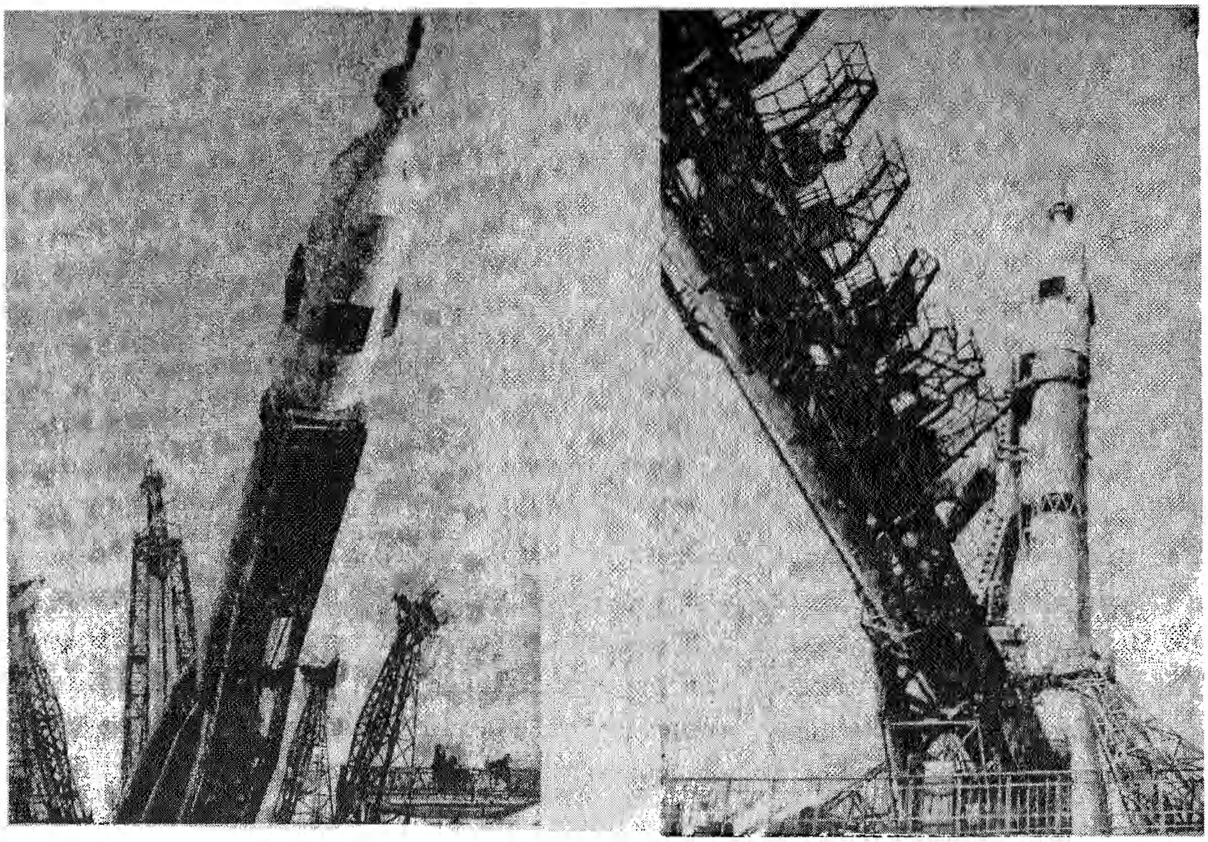
In order to maintain the spacecraft in this position for a prolonged period, additional expenditure of fuel and constant attention of the cosmonaut would be required. Therefore, the spacecraft is rotated around the spacecraft — Sun axis at a rate of several degrees per second. Because of the gyroscopic effect, the solar batteries will now remain oriented toward the Sun and the cosmonaut will be able to carry out the planned experiments.

Celestial Orientation of the Spacecraft

Precise orientation of the spacecraft in space is required in order to carry out orbital corrections and certain experiments and scientific observations. So-called celestial orientation is implemented for this. /49

The arrangement of celestial objects — the Sun, Moon, planets and stars — with respect to each other is known precisely at any moment of time. Therefore, if one of the spacecraft axes is directed, for example, toward the Sun, and the other axis — toward one of the celestial objects, the spacecraft will occupy a specific position in space.

The necessary data for celestial orientation are first fed into the programming-timing unit upon command from Earth. In this case, depending on the celestial object selected, for example, a specific star, one of the optical sensors is set in such a position that the angle between the axes of this sensor and the solar sensor corresponds to the relative location of the Sun and the given star.



Launch rocket with "Soyuz" spacecraft on launch pad.

The process of celestial orientation begins with a search for the Sun. The low-thrust jets are switched on and the spacecraft rotates around its longitudinal axis until the Sun enters the field of vision of the solar sensor. The other engines are then switched on and the spacecraft begins to rotate around a Sun-fixed axis until the solar sensor "locks on" to the given star.

The spacecraft is stabilized in this position and is then maintained thusly by the attitude control jets by commands from the gyroscopic instruments.

Orbital Correction

The "Soyuz" spacecraft make orbital corrections in order to carry out the flight program. What is the purpose of this operation?

Correction is carried out primarily to increase the flight altitude of the spacecraft. Atmospheric density 200 kilometers above the Earth's surface is negligible. However, despite the considerable rarefaction of the atmosphere, it still has a specific braking effect on a spacecraft of such dimensions as the "Soyuz." Orbital altitude decreases continuously and the braking effect of the atmosphere increases. This may lead in time to forced landing of the spacecraft.

Moreover, the purpose of correction is to ensure flight of the spacecraft above a given region at a specific time. The period of rotation of the spacecraft around the Earth increases as flight altitude increases. The spacecraft transfers to a lower orbit and the period of rotation around the Earth decreases under a specific braking impulse. By making the appropriate corrections, the flight of one spacecraft over the launch point of another may be guaranteed and it may observe orbit injection of the second spacecraft from space.

Depending on the flight program, correction may be accomplished both with the aid of the manual controls and automatically by using celestial orientation. Orbital correction using manual orientation /50
is accomplished in the following manner.

The necessary data for correction are transmitted from Earth and recorded in the onboard memory.

The cosmonaut presses the necessary key on the console. The inscriptions "Maneuver with manual orientation" and the "Optical sighting device for attitude control" light up. The spacecraft commander's hands rest on the control knobs and his attention is concentrated on the screen of the optical sighting device. The Earth slowly "sails by," passing on the screen. Operating the control knob, the cosmonaut switches on the appropriate thruster jets and rotates the spacecraft until the central portion of the screen coincides with a direction toward the center of Earth. Intersection has now coincided with this direction and the Earth's "course" passes by along

the spacecraft axis. The spacecraft is now oriented. A button is pressed and the inscription "Orientation by gyroscopes" lights up. This means that the gyroscopes have begun to rotate and their axes in space have occupied a position independent of the spacecraft hull. They have "memorized" the orientation of the spacecraft; commands are transmitted automatically to the engines upon any deviations of the spacecraft hull, which then return it to its initial position.

All further operations are now carried out automatically. The signal to rotate the spacecraft is transmitted from the onboard memory. The spacecraft must occupy a specific position in space. All these data are "remembered" by the automatic control devices. They then issue the command to switch on the engine at the calculated time.

The thruster engines operate to provide orbital correction and maneuvers. The force of inertia again presses the cosmonaut's body against his seat. Figures which characterize the extent of the developed velocity impulse "jump" across the indicator. Their course has now stopped. The spacecraft commander reports to the ground monitoring stations: "Correction was normal. The spacecraft is oriented correctly. The engine was cut off at the calculated time."

The cosmonaut's working day is coming to an end. Sleep is next. For this the cosmonaut again transfers to the orbital compartment, takes out his sleeping bag and, having strapped himself down on the couch, falls asleep. The spacecraft is in the "solar warping" mode.

Reentry and Descent in the Atmosphere

The multiton "Soyuz" spacecraft, moving at an orbital velocity of about 8 kilometers per second at more than 200 kilometers above the Earth, has enormous kinetic and potential energy. Orbital velocity must be reduced to accomplish reentry.

It would seem that this would require the same powerful engines which provided orbit injection of the spacecraft. However, complete /51
extinction of orbital velocity with the aid of retrorockets is not

feasible, since this would require a large increase in the weight of the spacecraft. Another method is used in which the retrorockets give the spacecraft a comparatively weak braking impulse, sufficient for orbital velocity to become somewhat less than orbit injection velocity. The spacecraft begins to descend and main braking takes place in the dense layers of the atmosphere due to atmospheric resistance.

The problem of returning a spacecraft to Earth from an artificial satellite orbit consists of two stages. The first stage is organization of reentry and flight of the spacecraft until it enters the dense layers of the atmosphere. The second stage is control of the spacecraft in the dense layers of the atmosphere and soft landing.

Commands, encoded in the appropriate manner, are fed from Earth into the spacecraft programming-timing unit during the orbit preceding reentry. These commands carry data about the time for switching on the retrorockets and about the force of the required braking impulse.

Before the retrorockets are fired, the spacecraft should be oriented in space such that its speed is reduced when the retrorockets fire. Orientation of the "Soyuz" spacecraft prior to deceleration may be accomplished either automatically or by manual control.

After the spacecraft has been oriented, the retrorocket nozzle is directed in the direction of motion of the spacecraft, and the attitude control system then maintains the spacecraft in this position. The retrorockets are fired at the precisely calculated time upon command from the programming-timing unit. A second command from the velocity variation meter cuts the retrorockets off so that subsequent reentry follows the calculated trajectory. The retrorockets are fired several thousand kilometers beyond the territory of the USSR.

The speed of the spacecraft is reduced, the compartments separate and the reentry capsule rushes toward the Earth. The remaining sections of the spacecraft burn up after entering the dense layers of the atmosphere. The reentry capsule itself, with the aid of the

engine of the descent control system, turns so that it will enter the dense layers of the atmosphere in a precisely calculated position.

The descent control system provides safe passage through the dense layers of the atmosphere during the last leg of the flight and precise landing of the reentry capsule in the given region of the Soviet Union.

What factors act on the reentry capsule and may be dangerous for the crew?

First of all, during deceleration in the dense layers of the atmosphere, high G-forces develop: travel speed during this leg of the flight decreases from several kilometers per second to several hundred meters per second. Consequently, the leg of intensive deceleration must be extended in time so that the accelerations developed and the G-forces caused by them do not exceed the maximum permissible for the human body, and, if possible, so that they are low. In this case the direction of the effect of G-forces is very important. /52

The reentry capsule should fly in a precisely stabilized position so that the cosmonauts are subjected to the least effect of G-forces.

The enormous energy of an object entering the Earth's atmosphere from space is almost completely converted to thermal energy. Even a part of this energy is quite enough for the reentry capsule to burn up completely. In order to prevent this, the spacecraft is equipped with a heat shield.

The characteristic feature of controlled descent, unlike ballistic descent, is the considerable reduction of G-forces and heat fluxes which act on the reentry capsule. However, the main advantage of controlled descent is that the reentry capsule lands with high accuracy in the given region.

Considerable variation of the landing points is possible during uncontrolled descent. This occurs for many reasons. In particular, deviations, even slight ones, in the force of the braking impulse, accuracy of spacecraft orientation during retrorocket firing, deviations of atmospheric density from calculated values at different altitudes, air currents and many others affect this variation. These factors are taken into account during descent of the capsule in controlled reentry, which ensures high accuracy of landing.

How is controlled descent accomplished?

The air flow around the reentry capsule is asymmetrical, due to which a lifting force develops. We say that such reentry capsules have aerodynamic efficiency, which is defined as the lift-to-drag ratio. Aerodynamic efficiency of reentry capsules, adapted for the severe conditions of descent in the atmosphere, is of course considerably less than that of aircraft.

By turning the reentry capsule around its longitudinal axis with the aid of the descent control engine, flight distance may be controlled. The absolute value of lifting force remains the same during such rotation, but its projection onto the vertical plane varies. The maximum effective value of lifting force occurs during zero roll angle. When the capsule is rotated by 90°, the effective value of /53 lifting force becomes equal to zero, and acquires a negative value with further rotation. This force compels a descent along a steeper trajectory. During descent the automatic control system regulates roll angle continuously, which ensures high accuracy of landing.

Implementation of control in the reentry capsules of "Soyuz" spacecraft, in addition to providing precise landing in the given region, permits a considerable reduction in maximum G-forces during the descent trajectory and a decrease in the weight of the heat shield.

When the reentry capsule reaches the given region at an altitude of about 10 kilometers, the parachute system is deployed. The soft landing engines are fired prior to landing.

5. THE WORLD'S FIRST EXPERIMENTAL SPACE STATION /54

The Experimental Orbital Station of the "Soyuz" Complex

Creation of the world's first experimental orbital station is a logical continuation of development of the program of manned flights of the "Soyuz" spacecraft. At the same time this success is based on the technical and scientific achievements of preceding space flights, during which new data were obtained on the properties of space and techniques of controlling objects in space.

Both the launches of the first satellites and the flights of Soviet cosmonauts and both the space walk of man and launches of automatic probes to the Moon and planets all created the strong foundation on which cosmonautics is now constructed.

The basic principles of design and configuration of the "Soyuz" spacecraft indicate the complex nature of solving the problems related to ceration of manned space stations. The "Soyuz" is simultaneously the prototype of orbital stations and transport spacecraft which will make regular trips between the stations and Earth and for rotation of crews and delivery of the necessary cargos.

The "Soyuz" spacecraft has an engine system, long-range radio communication equipment, attitude control system with a computer unit, life-support system and a crew compartment from which the space- /55 craft is controlled during flight and in which the cosmonauts return to Earth. Just such systems will be required by transport spacecraft to communicate with the orbital station, to approach it, for maneuvering in orbit and for docking with the station, and then return of the cosmonauts to Earth.

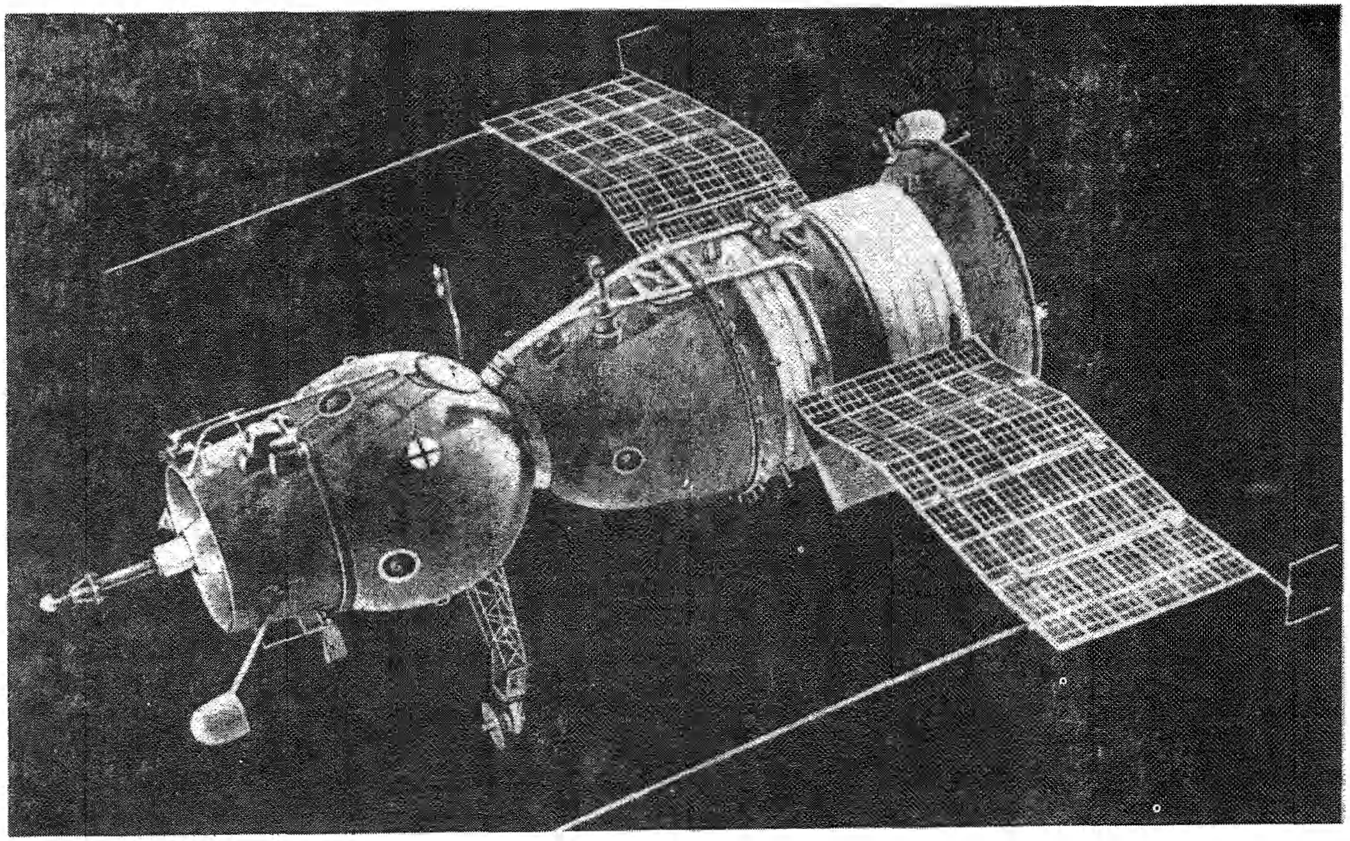
At the same time the "Soyuz" spacecraft may be considered as a model of an orbital station of the future. The "Soyuz" is the first spacecraft having two living compartments in it: the crew compartment and the orbital compartment. This considerably facilitates the work of the cosmonauts and expands their ability to control the spacecraft and to carry out scientific investigations. The orbital compartment of the "Soyuz" spacecraft is the prototype of the scientific laboratories and living quarters of orbital stations. The work of the cosmonauts in this compartment during flights will aid in determining the specifics of scientific research on board the station and in developing rational methods and procedures for conducting investigations under such conditions.

The joint flight of the "Soyuz-4" and "Soyuz-5" spacecraft was the next stage in creation of long-lived orbital stations and is a development of a whole complex of operations in creation and operation of them. Approach and docking of spacecraft is a practical solution of the problem of orbital station assembly from separate sections, launched sequentially into orbit, as well as solution of the problem of docking transport spacecraft to the station. The walks of cosmonauts in open space and the experiments carried out by them constitutes the development of autonomous life support systems, design of spacesuits and checking of the psychophysiological capacities and efficiency of cosmonauts. All this is necessary for ensuring future work of cosmonauts in open space on assembly of stations and conducting of scientific investigations. Finally, transfer from one spacecraft to another constitutes rotation of crews in the station and transportation of the necessary cargos, as well as operations in rescue of cosmonauts during certain possible emergency situations.

Let us now consider in more detail how the first experimental orbital station was created and operated.

Docking of Two Spacecraft

At 10:00 hours Moscow time on 15 January the "Soyuz-4" spacecraft, piloted by Vladimir Aleksandrovich Shatalov, passed over the Baykonur Cosmodrome.



"Soyuz" spacecraft with active docking unit.

At this moment the launch of the "Soyuz-5" spacecraft was underway. Its cabin contained three Soviet pilot-cosmonauts: spacecraft commander Lt. Col. Boris Valentinovich Volynov and the crew members — flight engineer, candidate of technical sciences /57
Aleksey Stanislavovich Yeliseyev and engineer-investigator Lt. Col. Yevgeniy Vasil'yevich Khrunov.

V. A. Shatalov observes the orbit injection of the new spacecraft through the portholes of his own craft. Animated conversations are taking place between the spacecraft and Earth. The joint flight of the two spacecraft begins. The commanders of the "Soyuz-4" and "Soyuz-5" spacecraft report that they have begun the program of joint experiments.

The flight of the "Soyuz-4" and "Soyuz-5" spacecraft is reliably supported by the ground command-monitoring complex, the network of monitoring stations which are located throughout the Soviet Union from its western boundaries to the Pacific Ocean. These stations, equipped with facilities for trajectory and telemetry measurements, television and communications, command radio stations and other means of control, observation and monitoring, carry out continuous operations on reception and processing of data coming from the spacecraft and maintain stable radio contact with the crews.

The scientific research vessels of the USSR Academy of Sciences, the "Morzhovets" and the "Nevel", which are located near the coast of Africa in the region of the Gulf of Guinea, and the "Kosmonaut Vladimir Komarov," located in the northwestern part of the Atlantic Ocean, also participated in the operations of the command-monitoring complex.

The morning of 16 January 1969 dawned. The crews of both spacecraft checked all the onboard systems. Permission for docking was given from the ground. The spacecraft first maneuvered for automatic approach. The inscriptions "Prepare for approach" and "Approach regime" light up on the cosmonauts' console. This means that the onboard radar system for search and guidance, which provides approach of the spacecraft, has been switched on.

During this leg of the flight, approach is automatic from a distance of several hundred kilometers and the role of the crews is reduced to observation and monitoring of the operation of the onboard systems. The "Soyuz-4" spacecraft was equipped with an active docking system and the "Soyuz-5" — with a passive system.

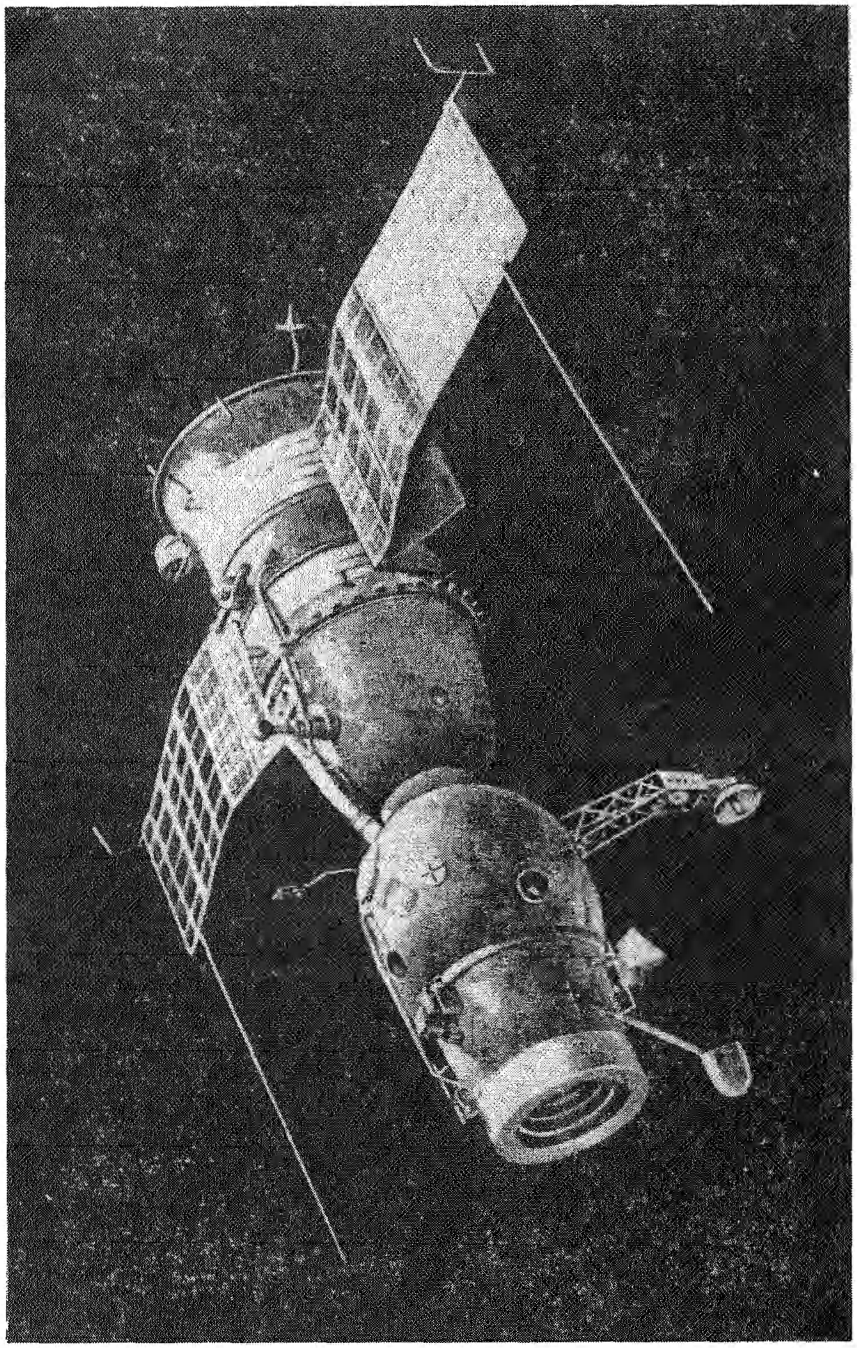
The radar system of the "Soyuz-5" spacecraft continuously emits signals, which are received by the corresponding systems of the "Soyuz-4" spacecraft. In this case the "Soyuz-4" does all the maneuvering necessary for approach, while the other spacecraft "tracks" it and orients itself so that their docking units are precisely aligned with each other.

During this period the signals incoming to the radar system of the "Soyuz-4" spacecraft are fed into the onboard computing units of the attitude control system, which issue commands to fire the engines, /59
taking into account the objective laws of orbital flight in order to fulfill the assigned mission with minimum fuel consumption.

Even a slight velocity increment in artificial satellite orbit to approach another spacecraft inevitably leads to an increase in orbital altitude. An impulse of the thrusters in a lateral direction in turn alters the orbital inclination. Only accurate operation of all automatic and attitude control systems can ensure effective approach of the spacecraft.

Beginning at a distance of 100 meters, Vladimir Shatalov takes over control of motion of the "Soyuz-4" spacecraft. The cosmonaut controls the operation of the appropriate jet thrusters. In this case, with the aid of the left control knob, he regulates the linear speed of the spacecraft, i.e., he decelerates or accelerates the spacecraft or decreases lateral speed.

Operating the right-hand control knob, the cosmonaut carries out the proper orientation of the spacecraft in space, by rotating it about its center of mass. The spacecraft have now approached within



"Soyuz" spacecraft with passive docking unit.

40 meters and have equalized their speeds. It is then that the following is reported: "Everything is normal. Distance 40 meters. Speed approximately zero. We have begun approach."

Tens of millions of people observe this remarkable experiment on the screens of their television sets.

Like two gigantic fairytale birds, glistening in the rays of the Sun, the "Soyuz-4" (call sign "Amur") and "Soyuz-5" (call sign "Baykal") spacecraft begin their approach. Ground control (call sign "Zarya") closely observes the docking process, which is taking place over the territory of the Soviet Union.

...This is "Amur." Do you permit docking?

"Zarya": Docking is permitted. Keep your reports brief if possible.

"Amur": "Baykal" is on the screen. Speed 0.25 meter per second. We are proceeding. I see the wings clearly.

"Zarya": All systems are go.

"Amur": Distance 20, speed 0.25.

"Baykal": A-okay, A-okay. We are awaiting contact.

"Amur": I am approaching. Everything is normal. Contact lock-on. Docking!

The docking probe touches the inner wall of the docking cone, slides along it and enters directly into the cradle. The inscriptions "Mechanical lock-on" and "Contact" light up. The spacecraft come into contact in their alignment planes. The clamps are engaged and the electric plug and socket units are joined.

"Amur": We are rotating. Alignment of the spacecraft is proceeding.

"Zarya": Everything is fine. The spacecraft is now stabilizing.

Docking proceeded excellently. The spacecraft have been aligned. Tightening continues. There is no relative motion between the space- /60 craft...The inscription "Docking completed" lights up.

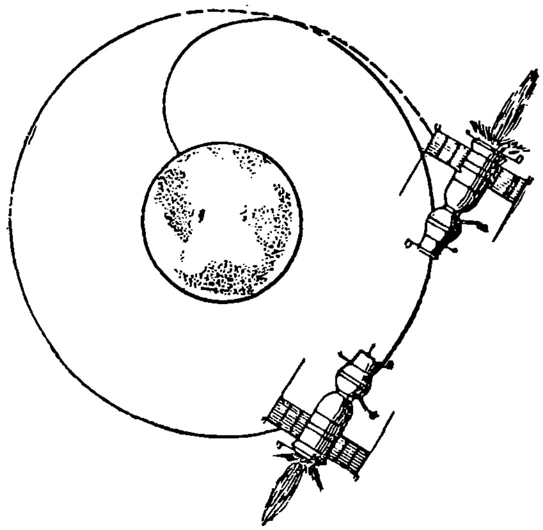
Thus, the world's first experimental space station, serviced by a four-man crew, was created in artificial satellite orbit.

The station was created by docking of "Soyuz" spacecraft, docking providing mechanical, power and a data integrity of the entire complex. After rigid mechanical docking the space station became a single unit with a common flight control system.

The control pulses of the correction thrusters and attitude control jets were now transmitted to the entire station and it obediently changed its position in space.

The common power system of the station was achieved by joining of the electric plug and socket units, which ensured connection of the electrical circuits of the spacecraft into the common electrical network of the space station. This provided important capabilities for concentration and redistribution of electric power according to the requirements of experiments. Moreover, connection of the electrical circuits permits the cosmonaut to control the station from any of the crew compartments.

Connection of the telephone circuits provided the space station with a complete information network. The cosmonauts were now able to maintain continuous two-way communications, and to exchange information from any of the four compartments of the station.



Orbit injection and docking of "Soyuz" spacecraft.

A space complex, consisting of four separate living compartments with an overall volume of 18 cubic meters, was in space for the first time. It is natural that the free space in the compartments had a favorable effect on the efficiency and well-being of the cosmonauts.

Having the two combined engine systems of the "Soyuz" spacecraft at its disposal, the experimental space station was fully capable of maneuvering, orbit correction and attitude control. /61

Space Walk of the Cosmonauts

One of the main experiments carried out during the functioning of the experimental space station was the walk of the cosmonauts in open space and transfer from one orbital compartment of the station to another. New spacesuits with autonomous life support systems were tested during this complex experiment, the airlock system was checked, assembly operations and scientific observations and still and movie photography were carried out, and the psychophysiological capabilities and efficiency of cosmonauts in open space were studied.

The airlock system on the "Soyuz" spacecraft is considerably more perfect than that on the "Voskhod" spacecraft, which was equipped with a special airlock from which Aleksey Leonov made the first space walk. The airlock on the "Soyuz" spacecraft fulfills the function of an orbital compartment. This same system provides return of the cosmonauts from space back to the station. The cosmonauts return to the orbital compartment through the previously opened outer hatch. After the outer hatch has been hermetically sealed, the orbital compartment is filled with a gaseous mixture for breathing and the cosmonauts remove their spacesuits.

This type of airlock system proved itself completely: it is distinguished by simplicity, economy and high degree of reliability.

There are now three in the orbital compartment. Volynov helps Khrunov and Yeliseyev into their space armor — new spacesuits designed for working in open space. The people on Earth, who are observing them with the aid of television, think that the cosmonauts accomplish this work comparatively easily. This is the result of meticulous preparation and multiple training sessions on Earth. Therefore, the work requiring close attention and special care also succeeds.

Having ascertained that the systems providing exit from the spacecraft are in working order, the cosmonauts report to the commander that they are ready. Volynov transfers to the crew compartment. The hatch connecting the crew and orbital compartments is closed and the orbital compartment is depressurized.

The internal pressure of the cosmonauts' spacesuits is maintained at a specific level so that, on the one hand, it does not threaten the health of the cosmonauts, and on the other — it does not constrict their movements.

...The exit hatch opens. The cosmonauts leave the "Soyuz-5" spacecraft one after the other. Autonomous backpack regenerative systems maintain the necessary chemical composition of the gaseous mixture for breathing, humidity and provide the appropriate heat /62
regulation in the spacesuits during their stay in open space.

Heat regulation is very important, since a man in space expends considerably greater efforts, and consequently energy, for any movement than he does under ordinary conditions. All this is related to liberation of a large amount of heat and may lead to overheating of the body. The easiest method of locomotion is "walking" on the hands, for which special handrails were installed between the spacecraft.

The multilayered elastic membrane of the spacesuit of a rather strong material reliably protects the cosmonauts from unfavorable factors. They wear pressure helmets with special glass for observations, above which a movable visor is mounted, which acts as a solar light filter. Articulated connection of the spacesuit elements provides adequate freedom of movement of the cosmonauts.

A modern spacesuit is not simply a special suit, but a complex unit, designed to provide life support and efficiency of man in open space.

Only a few centimeters from the body surface of the cosmonaut beyond the multilayered membrane of the spacesuit are the vacuum and cold of space, the scorching rays of the Sun and meteoritic dust particles which travel at enormous velocity. The entire system protecting the cosmonaut against these lethal factors of space is completely autonomous. The cosmonaut is linked to the spacecraft only by a thin lifeline which contains the conductors for telephone communication and for the system for monitoring the cosmonaut's health. Work of the cosmonauts in open space, which continued for more than an hour, confirmed the correctness of the basic principles and design solutions employed in development of the spacesuit. The cosmonauts gave high marks to the spacesuits and autonomous life support systems: the spacesuits did not restrict their movements, ventilation in them was good, there was no overheating of the cosmonauts' bodies and the windows of the pressure helmets did not fog up.

During their walk in space the cosmonauts investigated various problems related to purposeful activity of man in space.

While outside the spacecraft, the cosmonauts maintained continuous communication with the spacecraft commander through the lifeline. The spacecraft commanders observed the movement and work of the two cosmonauts with the aid of television cameras mounted on the spacecraft hull.

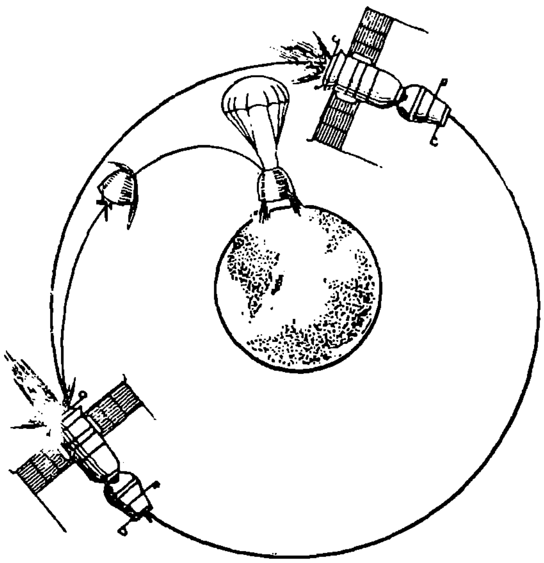
After emerging into open space, the cosmonauts carried out external inspection of the station hull, the docking unit and solar batteries and observed operation of the attitude control jets. Removal and installation of the bar from the movie camera, installation and stowing the handrails for emerging from the orbital compartment and entry into it, installation and stowing of the television tubes, simulation of certain repair operations on assembly of orbital stations — this is a far from complete list of the operations which the cosmonauts carried out. /63

Weightlessness considerably complicates fixing of the body in a specific position in space, which is especially manifested when performing operations requiring high precision (for example, astronomical observations).

Ye. V. Khrunov, having completed the planned work cycle, approaches the open hatch of the orbital compartment of the "Soyuz-4" spacecraft. A. S. Yeliseyev follows him into the spacecraft.

V. A. Shatalov meets the cosmonauts in the orbital compartment and helps them to remove their spacesuits. There joyous excitement, exchange of impressions, letters and newspapers which Khrunov has brought from Earth through space for Shatalov.

There is no doubt that the experience of the purposeful activity of the cosmonauts, acquired during operation of the station, yielded much new data for study of a number of psychological and physiological problems related to functioning of man in open space. Thus, for example, it becomes clear that the psychological barrier in the direct encounter of man and open space (so-called "agoraphobia) has been overcome completely. The complex of special training sessions, development of exit from a model of the spacecraft under conditions of weightlessness, created briefly during special flights of flying laboratories and parachute jumps — all this prepares the cosmonaut for walking in space to such an extent that none of the anticipated psychological effects was observed. Thus, the sensations which



Orbital correction, retorfiring and descent of the spacecraft.

Yevgeniy Khrunov experienced upon emerging into space were similar to those experienced during parachute /64 jumps.

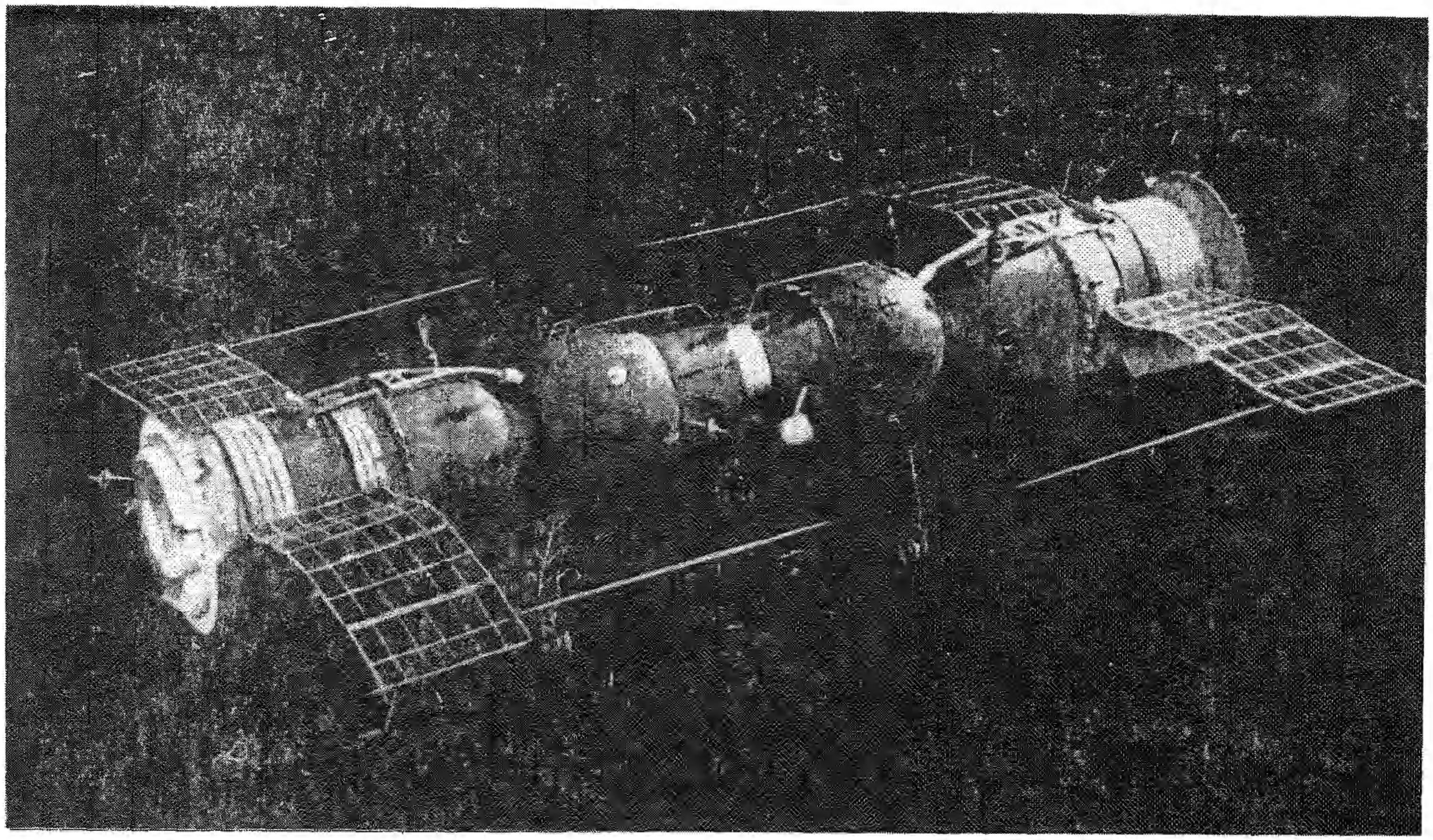
The station continues its flight. Vladimir Shatalov carries out experiments on control of the station. It is easy to control the station and it responds to the slightest movement of the control knob.

Shatalov orients the station in a specific position. Undocking may begin. The spacecraft, as if unwilling, slowly move away from each other. Boris Volynov remains alone in the "Soyuz-5" spacecraft.

After undocking the "Soyuz-4" and "Soyuz-5" spacecraft continue their group flight. The crews of both spacecraft successfully carry out their work program. The new crew members of the "Soyuz-4" spacecraft, cosmonauts Yevgeniy Khrunov and Aleksey Yeliseyev have become familiar with their work positions, check the operation of the spacecraft systems and carry out the observations and experiments envisioned by the flight program. Thus ended this historical day of 16 January 1969.

Scientific Investigations and Experiments

During the flight of the "Soyuz-4" and "Soyuz-5" spacecraft, as well as during the flight of the experimental space station, the cosmonauts carried out a broad complex of different scientific investigations. This experiment indicates that the scientific investigations in space by a collective of investigators is extremely effective and permits complex experiments of varied nature. The



First experimental "Soyuz" space station (model).

cosmonauts carried out observations of the Earth and atmosphere, investigated the effect of space factors on the spacecraft system and conducted celestial navigation investigations, physical experiments and medical and biological investigations.

Meteorological observations may be cited as an example of the multifaceted investigations of Earth carried out by the cosmonauts. They observed the cloud cover of the Earth, typhoons and cyclones. Periodic or continuous observation of the meteorological situation permits analysis of the dynamics of different processes, for example, the birth of a cyclone, the speed and direction of motion of a hurricane, etc. These investigations aid forecasting of the various meteorological phenomena and will control them in the future. Observations of the snow and ice cover of the Earth were also carried out. These observations are useful for predicting the characteristics of snowmelts and floods, as well as for study of ice drift, determination of the ice cover and freeing water basins of ice. Observations were carried out from space to study the Earth's geological structure. The cosmo- /66
nauts observed and photographed the various types and shapes of relief, which provides valuable information for subsequent compiling of topographical maps, in particular, of mountain regions which are difficult to reach.

Observations of the daytime and twilight horizons of our planet, as well as investigations of the Earth's brightness at different angles of inclination of the Sun are of great interest. The richness of color tones of "space sunsets" is explained by the non-uniformity of the properties of the Earth's atmosphere and by the degree of scattering and absorption of solar radiation by the atmosphere. Aerosol layers — accumulations of solid particles suspended in the atmosphere, the presence of which explains the brightness layers discovered by the cosmonauts on the Earth's "morning" and "evening" horizons — play an important role in these processes. These observations are especially important not only in study of the atmosphere, but also for developing the accuracy of space navigation, when the edge of the Earth is selected as one of the reference points.

The cosmonauts conducted celestial navigation investigations, observations of the astral sky during both day and night and photographed the night sky in a direction opposite the Sun. Experiments were carried out on study of the initial stages of the development of comet tails, observation of luminescent particles and on investigation of the Earth's magnetic field.

Primary cosmic rays and their multicharge component were also investigated and the relative distribution of helium and tritium isotopes in cosmic rays was studied. The effect of micrometeorites on the structure and system of the spacecraft was investigated and the intensity of penetrating radiation was measured.

A complex of medical and biological investigation comprised a considerable part of the overall flight program of the "Soyuz-4" and "Soyuz-5" spacecraft. It was known that man in space finds himself in a completely unusual environment. In connection with this the entire functioning of the human organism is readjusted: the energy, water-salt and hormone metabolism are altered and the functioning of the cardiovascular, respiratory and digestive systems, and central nervous system change.

Although these changes are not a threat during short space flights, careful study of them permits development of procedures to counteract the unfavorable factors of space during future prolonged flights. Careful and preliminary special preparation of the cosmonauts is of special importance in this regard. Thus, for example, a high level of physical training broadens the compensatory capacities of the organism under mental and physical stress, as well as the effects of the dynamic and static factors of space flight.

To study the dynamics of changes which take place in the cosmo- /67
naut's body during activity in space, data about the state of the cosmonaut's organism is processed operationally and transmitted to flight control stations by a medical monitoring system.

Investigations on selection of the optimum food ration for cosmonauts, corresponding to the physical loads on the organism, are also of great interest. The suggested space menu completely satisfied the cosmonauts. What was the ration of a cosmonaut? This is indicated by the labels on the packages: "Liver pate," "Roast beef," "Chocolate," "Pastry," "Cheese." All this was washed down by fruit juice from special tubes. It is delicious and nourishing. The provisions are vitamin-supplemented. The daily food intake of a cosmonaut is 2400 - 2700 kilocalories, and special emphasis was given to increased consumption of high-quality proteins and carbohydrates.

Space flights provide interesting data on human biological rhythm. Selection of the proper sleep and wakefulness pattern, frequency of eating, etc., is of great importance in providing high efficiency of the cosmonauts. Preliminary investigations already show that, despite the high specifics of life in space, it is desirable to maintain rhythms similar to those on Earth.

A great deal of work was carried out to provide radiation safety during training for the flights of the "Soyuz" spacecraft and during the flights themselves. Forecasting of solar activity for the scheduled time of the flight was carried out. Measures were taken both before and during the flight for antiradiation protection.

The entire complex of medical and biological investigations is directed toward study of the problems of adaptation of man to space conditions. In this regard the flights of man into space have not only scientific and applied, but philosophical importance as well, if we consider the living organism in relation to its environment, and this environment is being considerably expanded and complicated by man's emergence into space.

A large amount of data, which was processed by tens of scientific collectives, was derived during preparation and conducting of investigations on creation of an experimental space station. These investigations provide the most valuable material for improvement of space

technology and make an important contribution to geophysics, geology, physics of the atmosphere, meteorology, astronomy and other sciences.

6. WHEN THERE ARE THREE SPACECRAFT IN ORBIT /68

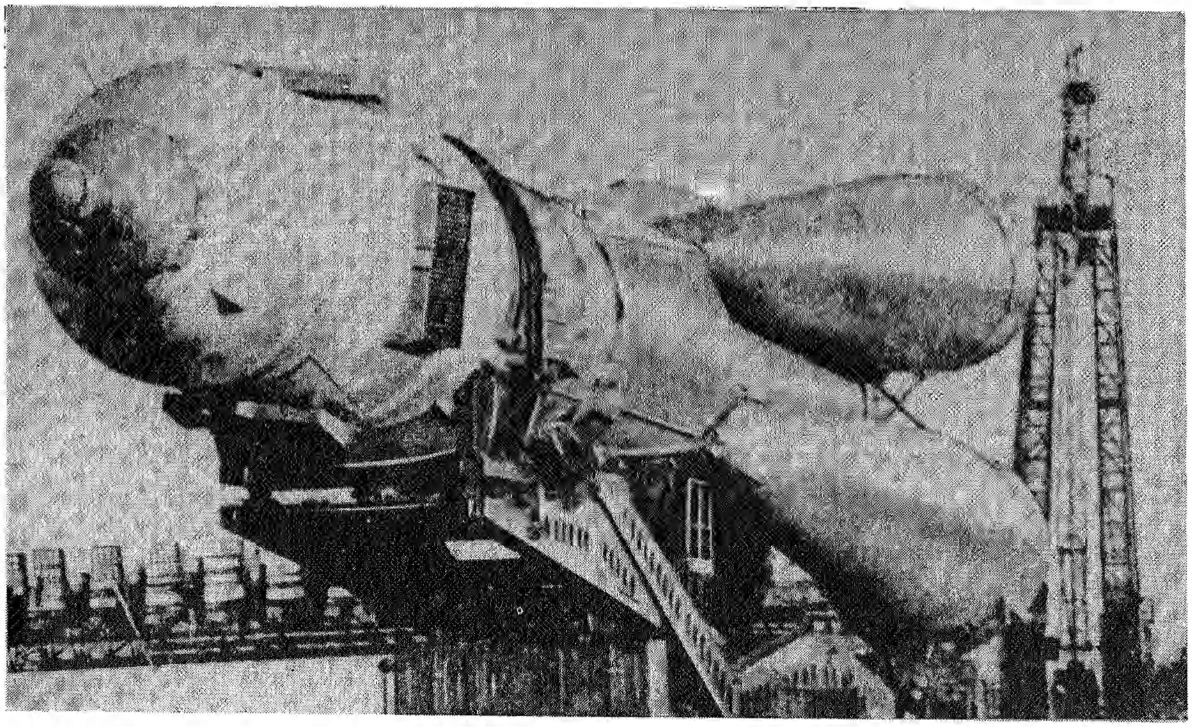
Maneuvering of Spacecraft

On 11 October 1969, the "Soyuz-6" spacecraft, piloted by Lt. Col. Georgiy Stepanovich Shonin and Flight Engineer Valeriy Nikolayevich Kubasov, was injected into orbit. A day later the "Soyuz-7" spacecraft was launched with three cosmonauts on board: Anatoliy Vasil'yevich Filipchenko, Vladislav Nikolayevich Volkov and Viktor Vasil'yevich Gorbatko. On 13 October, a third spacecraft, the "Soyuz-8" was launched with a crew consisting of Vladimir Aleksandrovich Shatalov and Aleksey Stanislavovich Yeliseyev.

The spacecraft flew as a group for 7 days, during which the cosmonauts performed an extensive program of scientific and technical experiments. The history of cosmonautics had never known such excitement in space.

The main tasks confronting the spacecraft crews may be formulated as follows: joint maneuvering using manual control, development of methods of autonomous navigation, and observation and photography of the Earth's geological and geographical objects. Certain improved spacecraft systems were tested during the flight and complex medical and biological investigations and meteorological observations were carried out.

The "Soyuz" spacecraft were launched from the Baykonur Cosmodrome, /70 one of the largest in the Soviet Union. The rate of the launches by the powerful launch rockets at one-day intervals predetermined intensive operations of all services of the launch complex. Methods of preparing the most complex systems of launch rockets and spacecraft for flight within such compressed time periods were tested for the first time in history. This was a type of rehearsal for launches of future series of transport spacecraft for the assembly of large orbital space stations.



Launch rocket with "Soyuz" spacecraft.

When there were three spacecraft in orbit, the command-monitoring complex of the Soviet Union was faced with an unprecedented load. The added work of the Earth-space system, demonstrated throughout the entire flight, is no less important for the development of space navigation.

What is the complexity of simultaneous control of three manned spacecraft? During the flight, the "Soyuz" spacecraft were sometimes located at a considerable distance from each other and sometimes approached to within several hundred meters. In the first case the tracking station, having completed radio contact with one spacecraft, had to rotate its antennas within the shortest possible time in the direction of another spacecraft, located within the zone of radio visibility, and make adjustments for working with it.

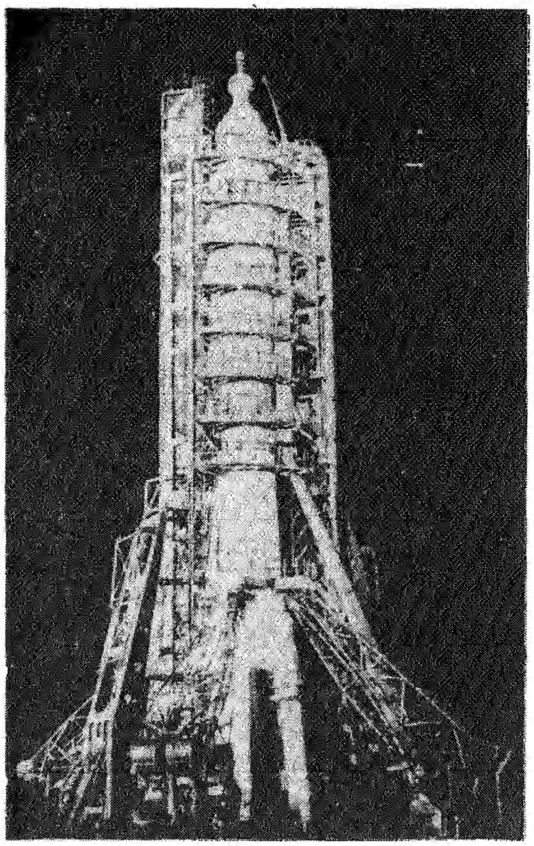
When the spacecraft were located within several kilometers of each other, they entered the "field of vision" of the radio beam simultaneously. Therefore, the communication session was literally

scheduled in seconds. During the brief radio communication session, it was necessary to receive telemetry data, to transmit commands to the spacecraft, and to make a television report. At the same time, the spacecraft maintained intensive radio communications outside the zone of radio visibility from the Soviet Union.

Several radio bands were utilized for communications. Short waves were employed for long distances. Continuous communications were carried on with the aid of ultrashort waves within the range of direct radio visibility. Therefore, when the spacecraft passed over the territory of the Soviet Union, the ground stations transferred each spacecraft to each other, like a relay baton, ensuring continuous communications with it.

The assembly of large orbital stations is a problem of the near future. This requires extensive maneuvering of spacecraft. Some of them will deliver the structures for future stations to the designated orbit, some will deliver fuel and provisions, and others will deliver the crews of the orbital space systems. This is why so much attention was devoted to the joint maneuvering of the three manned "Soyuz" spacecraft. The main problem solved by the three crews consisted of coordinated approach of the spacecraft from a distance of several hundred or even thousand kilometers to a distance of several hundred meters.

During the maneuvering in orbit, methods were tested for interaction with the ground complex, whose stations are distributed throughout the Soviet Union, as well as with the research vessels of the Academy of Sciences, which were located at different points at sea. Data from trajectory measurements were fed continuously from the tracking stations to the computer coordination center, where they were processed automatically on electronic computers. The space situation was carefully analyzed according to the mutual position of the spacecraft. The initial parameters received for approach maneuvers were transmitted from the ground to the spacecraft and recorded in the onboard memory.



Launch rocket with "Soyuz" spacecraft on launch pad.

The powerful engines of the spacecraft were fired automatically at the calculated time. After operating for the prescribed period, they cut off automatically. As a result, the spacecraft transferred to another orbit, ensuring its approach to the other spacecraft.

Successful maneuvering permitted the "Soyuz-6," "Soyuz-7" and "Soyuz-8" spacecraft to approach each other repeatedly to such close distances that the cosmonauts were able to carry out necessary measurements and observations of the maneuvering of their comrades.

Scientific and Technical Experiments and Observations

While carrying out extensive maneuvering during group flight, the cosmonauts simultaneously completed an extensive program of experiments of importance to the national economy and medical and biological experiments.

They made meteorological observations over practically the entire portion of the globe, encompassed by the spacecraft trajectories. The cosmonauts photographed cloud cover distribution, observed the birth of cyclones and tracked their further development and direction of travel. These data were systematically computed in the Hydrometeorological Center of the Soviet Union.

Observations and photography of the Earth's surface in different regions of the spectrum permitted not only the prediction of threatening natural phenomena — hurricanes, floods and dust storms. These investigations are also of great importance for solving the varied problems of geology, goebotany, hydrology and other Earth sciences.

One of the most promising trends in the analysis of space photographs is using them to compile geomorphological maps of small and medium scales, as well as geomorphological ranging. Practically all types and many forms of relief, including underwater forms, can be distinguished on such photographs. Therefore, the cosmonauts of the three spacecraft photographed characteristic sections of the Earth's surface according to the program of geological and geographical investigations. In particular, they investigated in detail the relief of mountain massifs, the coast lines of the Caspian Sea, the Volga Delta and forests of the USSR. They studied the reflectivity of forest massifs and desert regions of the planet.

Besides the extensive program of still and movie photography of the Earth's oceans and cloud cover, the crews made a large number of navigational measurements.

Procedures were tested for visual celestial orientation by stars of the fourth and fifth magnitudes, making it possible to calculate the precise position of the spacecraft on the space trajectories without the use of ground facilities. After all, in future interplanetary trajectories, the larger stars may be obliterated by the Sun or be located under conditions unfavorable for observation.

The program of developing procedures for autonomous navigation included observation and photography of the daytime and twilight horizon, measurement of the intensity of illumination of the daytime and shaded surface of the Earth, brightness of stars in different bands of the visible spectrum, and also evaluation of the visibility of the Moon and stars on the background of the horizon. The possibilities of manual orientation were calculated by using an optical sighting device under twilight conditions and in the Earth's shadow.

Welding of Metals in Orbit

On 16 October 1970 the crew of the "Soyuz-6" spacecraft conducted a unique experiment on welding metals under space flight conditions. Prior to the beginning of welding, the spacecraft commander, Shonin, opened the hatch to the spacecraft cabin. On the 77th orbit, he depressurized the orbital compartment, in which was installed a unique piece of technological equipment designed to investigate various methods of welding metals in a high vacuum and during weightlessness.

Flight Engineer Kubasov regulated the operating modes of the autonomous experimental device "Vulkan" from the control console in the crew cabin. This device, connected to the spacecraft only by a telemetry cable, consisted of two units. The first contained various welding devices and the second — power supplies, control instruments, measuring and conversion systems and automatic aids and communication facilities. They were in a pressurized compartment filled with nitrogen.

After a high vacuum had been established in the orbital compartment, the cosmonaut switched on an automaton, adjusted for low-pressure (plasma) compression arc welding. The device was then switched to electron beam welding. The third mode of the "Vulkan" was consumable-electrode arc welding.

Thus, the world's first practical technological process, related to heating and fusion of metals, was accomplished in orbital flight. This success was preceded by prolonged ground investigations which permitted the design of small welding devices for installation in spacecraft. The results of the experiments permit certain preliminary practical conclusions.

It was determined that under conditions of weightlessness considerable changes occur in the microstructure of welds, related to the absence of gravity. Welded joints are strengthened somewhat, but in some cases local porosity of the welds is observed. It turned out that, during consumable-electrode arc welding under conditions of

weightlessness, special measures are required which would ensure reliable transfer of the metal from the electrode to the bath. A vacuum complicates ignition of the arc discharge as well. Therefore, special methods of ignition were developed for welding in space.

It is important that the results of the investigation and developments, accomplished during preparation for space welding, have already been applied in the national economy of the country. For example, techniques of vacuum arc welding have been improved, and a small-size and highly productive apparatus has been created for joining metals by an electron beam and compressed arc.

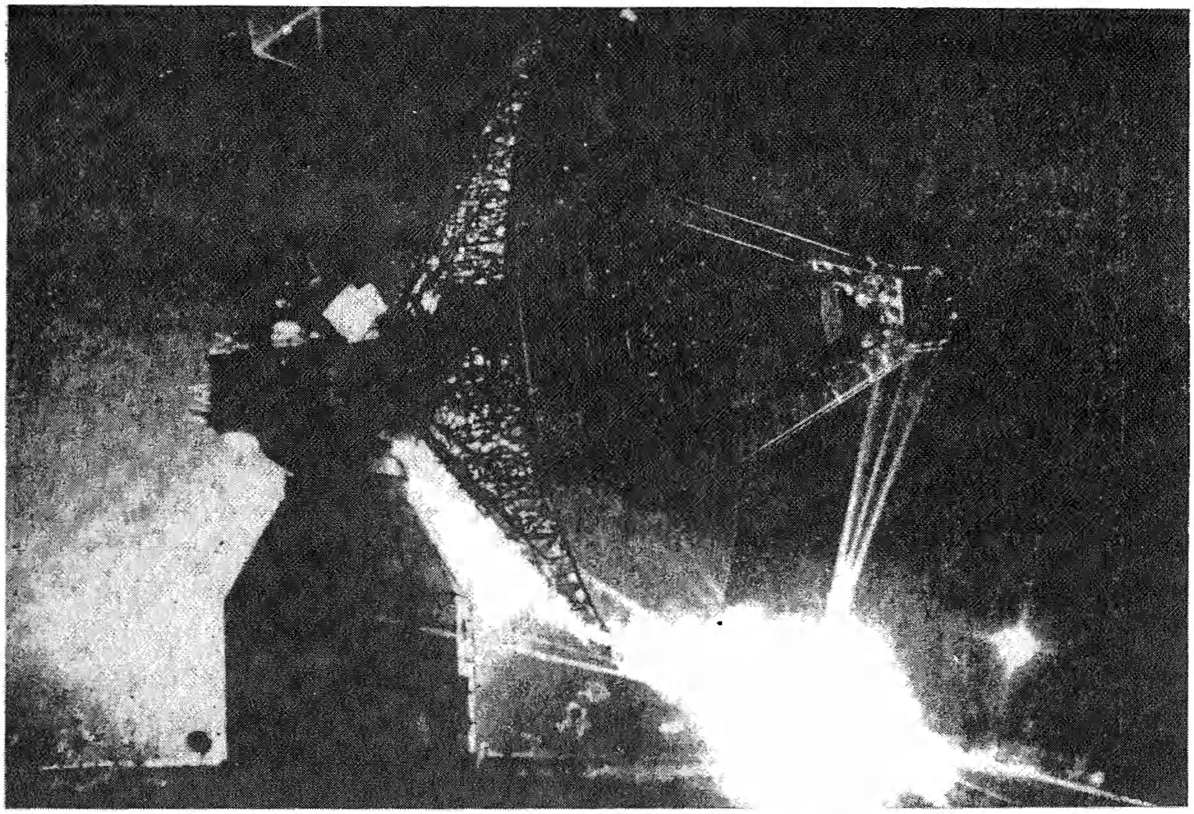
The successful experiment in welding on board the "Soyuz-6" /74 spacecraft opens up future prospects for improving techniques in the assembly of large orbital stations. The energy for welding operations in orbit may be obtained from such an inexhaustible source as that of the Sun.

It is difficult at present to foresee what type of welding will be most promising. Therefore, it is not excluded that such a progressive method of bonding materials as diffusion welding may possibly become widespread. After all, the conditions of space are ideal for this type of welding.

7. "SOYUZ-9" IN WORKING ORBIT /75

Medical and Biological Investigations During Prolonged Space Flight

On 1 June 1970, the "Soyuz-9" spacecraft was injected into an artificial Earth satellite orbit with a crew consisting of spacecraft commander Col. Andriyan Grigor'yevich Nikolayev and flight engineer Vitaliy Ivanovich Sevest'yanov. The record space flight in which the cosmonauts took an active part lasted for 424 hours. After completing an 18-day program of scientific experiments and observations, the "Soyuz-9" made a precise landing in the calculated region.



Radio complex of the spacecraft flight control center at night.

The most important part of the flight was the extensive medical and biological investigations studying the effect of prolonged space flights on the human body. Moreover, special attention was devoted to measures on retention and maintenance of a good functional state of the organism and a high level of efficiency of the cosmonauts.

What did this space flight, unprecedented in duration, yield that was new for cosmonautics? How did the cosmonauts tolerate the several days of "confinement" and the conditions of weightlessness during orbital flight? The answers to these questions could be given by scientists after careful analysis of the data obtained.

It is natural that the main attention during such a prolonged flight was devoted to medical and biological problems. It was known from previous space flights that cosmonauts, even during less prolonged "excursions" into space, feel the effects of space factors to a certain extent.

It was established that the spacesuits used by the cosmonauts during the initial flights not only constrict their movements, but also cause "numbing" of individual parts of the body. Other comparatively insignificant physiological changes also occurred in the human body. In particular, the calcium balance in the bones was disrupted, and partial changes in blood composition and dehydration of the body were noted. During the final stages of the flights, torpidness of movements and decreased responses began, and disruptions in the function of the vestibular analyze_ were observed. Typically, these and other deviations are at times purely of an individual nature. Therefore, it was important for scientists to determine the main trends of "shifts" in the human body during prolonged space flights. /77

In order to compensate for the possible unfavorable effects of weightlessness, the crew of the "Soyuz-9" spacecraft regularly performed a cycle of gymnastic exercises in the spacious orbital compartment. A special weighted suit forced the cosmonauts to expend additional efforts, simulating the effect of the force of Earth's gravity. The crew exercised with an expansion device, the tension of which required a slight exertion of 10 kilograms according to Earth standards.

However, under conditions of weightlessness the cosmonauts were forced to spend more time on gymnastics than was previously planned. In turn, the medical support services saw to it that the complex of physical exercises were fulfilled completely.

Careful medical and biological monitoring of the health of the "Soyuz-9" crew members was accomplished throughout the flight. Pulse, respiration frequency and blood pressure were measured regularly, the cardiovascular and nervous systems were investigated and water-salt metabolism was monitored. The data were regularly transmitted to Earth and studied closely. Stable radio communication was maintained with the cosmonauts, and television permitted observation of their work and rest several times daily.

The cosmonauts' efficiency while performing work operations was investigated during the flight. The quality of performing special tests was analyzed.

Moreover, certain experiments were conducted with the active participation of the cosmonauts in accordance with the program of biological investigations. The overall aim of these investigations was to study the effect of weightlessness on growth, development, and heredity of various types of living organisms. Experiments were conducted on Drosophela, wheat nodules, barley, onions, and Chlorella and blue-green algal cultures.

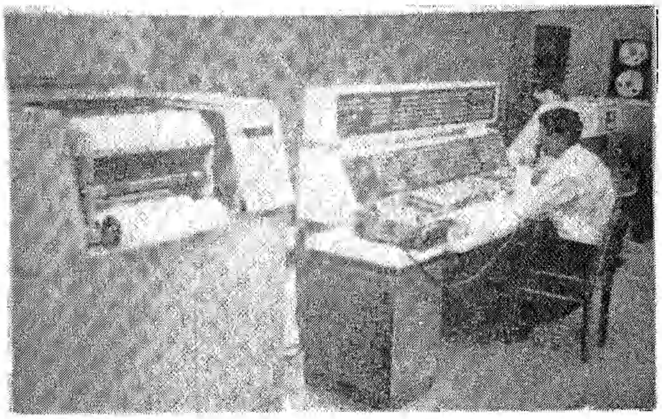
The cosmonauts felt fine during the flight. Despite the heavy /78 load of the flight program, they retained their efficiency at a high level. However, they sometimes noticed some tiredness, after performing complex experiments and after a busy work day, which disappeared completely after sleep.

The cosmonauts' very interesting and valuable observations of their condition during the flight, like the data of objective investigations, made it possible to obtain important data on the characteristics of adaptation of the human organism to weightlessness.

A certain amount of time was required at the beginning of the flight to develop new skills in performing movements, especially for moving about in the spacecraft. By the third or fourth day of the flight, the cosmonauts were already confidently moving about inside the spacecraft.

The processes of adaptation to weightlessness were manifested in the area of the vegetative sphere as well. Thus, for example, pulse frequency during the third to sixth orbits had already reached preflight levels and then remained at a lower level.

Pulse and respiration frequency and electrocardiogram indices had stabilized by the third to fourth day of flight. In this case, the systolic frequency of A. G. Nikolayev varied within the range of



The computer complex of the Space Flight Control Center continuously processed the data received from "Soyuz-9."

68 - 80, and that of V. I. Sevast'yanov — 60 - 70 beats per minute, naturally increasing when performing physical exercises, as well as during certain complex experiments. Pulse frequency decreased somewhat during sleep.

It is interesting to note that A. G. Nikolayev's pulse, compared to his first flight in the "Vostok-3" and during the flight of the "Soyuz-9" spacecraft, was somewhat lower during comparable legs of the flight. Arterial pressure at rest hardly varied throughout the flight. The reaction of the heart to standard physical loads did not undergo any appreciable changes throughout the flight.

The cosmonauts reported that, during the initial phase of the flight when they abruptly inclined their body or head, they experienced a sensation similar to that which they felt on the ground during vestibular loads, which apparently indicates some decrease in the threshold of vestibular responses during weightlessness.

Their appetite during the flight was good. Thirst was somewhat reduced. The amount of water consumed (taking into account the water in their food) was equal to 1.6 - 1.8 liters per day.

The life support systems of the "Soyuz-9" spacecraft efficiently maintained the given conditions of gaseous composition, temperature, humidity and atmospheric pressure in the spacecraft compartments. The cosmonauts were provided with food in the form of natural products and the average daily caloric content of their rations was about 2600 kilocalories. The spacecraft contained a food heater. The cosmonauts noted the favorable effect of having hot coffee in the morning. For lunch they usually heated up such common first courses as cook's

soup or green borscht. Rational structuring of the work-rest cycle played an important role in maintaining efficiency.

Valuable data were obtained during postflight observation and examination of the cosmonauts. Marked changes in the motor sphere were detected in the cosmonauts on the day of landing. Their sensations were similar to those observed during the effects of G-forces of 2 - 2.5 on the centrifuge. The head, extremities and other parts of the body seemed unusually heavy, and the cosmonauts felt their weight. This condition continued for about two to three days. Statics and movements had practically returned to normal by the tenth day after return to Earth.

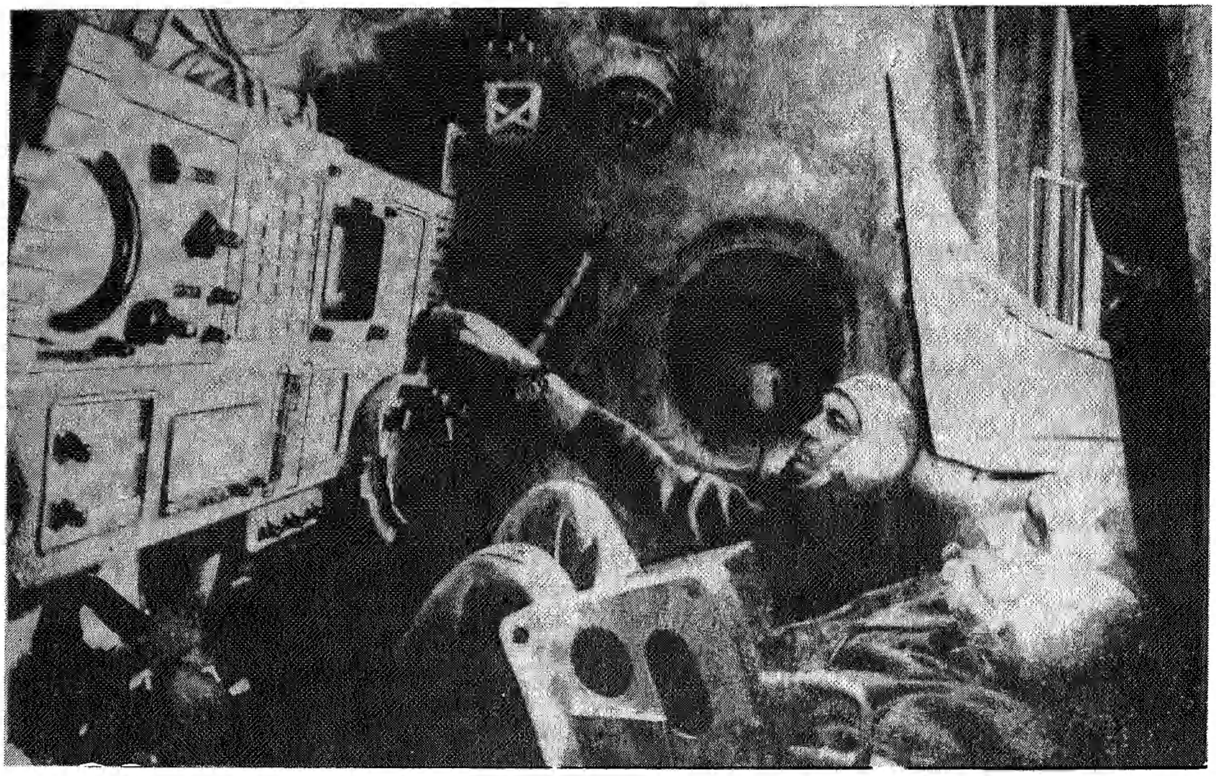
And generally, the changes in physiological functions had basically returned to normal within ten days after the flight.

Thus, scientists concluded that adaptation to the ordinary conditions of existence on the ground after prolonged periods of weightlessness proceeds with certain difficulties, and is apparently achieved by greater stress on the physiological systems than adaptation to weightlessness.

Maneuvering and Navigation Measurements

The working day of the crew usually comprises 14 - 16 hours. Besides the medical and biological investigations, further testing of spacecraft manual control systems and navigation instruments was carried out during the flight, and complex checking and testing of practically all onboard systems were accomplished under the conditions of prolonged space flight.

The cosmonauts corrected their orbit three times using the manual attitude control system. As already noted, the "Soyuz" spacecraft may be maneuvered automatically, by commands from ground control, /81 and with the aid of manual control. The latter method was tested



"Soyuz-9" commander A. G. Nikolayev (foreground) and flight engineer V. I. Sevast'yanov in the cabin of the spacecraft.

especially carefully in preceding flights. Moreover, the cosmonauts, observing the Earth with the aid of the optical sighting device, oriented the spacecraft manually.

The automatic system was then switched on. The gyroscopic instruments "held" the spacecraft in its initial position, and the powerful rocket engine fired at the given moment upon command from the programming-timing unit. The spacecraft transferred to higher orbits, ensuring such a prolonged flight.

The dynamics of orbital flight and the program of scientific experiments required that the cosmonauts stabilize the spacecraft periodically with respect to a given direction toward a selected star or some ground reference point and that they "twist" the spacecraft toward the Sun in order that the solar batteries be exposed to

a continuous luminous flux for a prolonged period. In this case, special significance was given to developing methods of autonomous navigation.

During the flight of the "Soyuz-9" spacecraft, the crew repeatedly made navigation measurements, using in particular, a star sensor of new design. The cosmonauts calculated the orbital parameters and geographical latitude of the point above which the spacecraft was flying at the moment from the position of a selected star above the horizon. The difficulty of making such measurements is that the spacecraft is moving continuously and, consequently, the measured angles also "drift." Therefore, the measurements must be made many times.

The experiment with the star sensor was performed during one of the working days for two whole orbits. In view of the complexity of the measurements, communication was not maintained with the spacecraft during this period.

After receiving instructions from ground control to perform this experiment, the cosmonauts first turned the "Soyuz" spacecraft in a direction opposite the Sun. The star Vega in the constellation Lyra, selected according to the program, was then found. In summer, the Sun and Vega are located in opposite direction with respect to the Earth. The large and bright star Vega is clearly distinguished against the night sky. Therefore, this star was selected.

Having found Vega, the cosmonauts turned the spacecraft with the aid of the attitude control jets, so that the star came within the field of vision of the star sensor. The design of the sensor permits its adjustment to a specific magnitude of a celestial body. In the given case, it was adjusted to Vega and, consequently, did not respond to other light sources of greater or lesser magnitude.

The inscription "Lock-on" lit up, confirming the reliable operation of the sensor. This experimental device on the "Soyuz-9" spacecraft was not connected to the control systems. Therefore, keeping

the star in the center of the field of vision of the sensor, the cosmonauts stabilized the spacecraft manually. Moreover, they /82 simultaneously photographed the technical characteristics of the instrument under the real conditions of space flight.

The spacecraft passes to the daylight side of Earth. However, orientation on Vega continues to be maintained. A strip of the brightly illuminated Earth falls into the field of vision of the sensor. The inscription "Forbidden" lights up immediately. This means that the sensor has responded correctly to extraneous emissions, registering only the given star. Henceforth, it will "notice" only Vega.

The cosmonauts transfer stabilization control of the spacecraft to the gyroscopic instruments, which must now "hold" the star in the field of vision of the sensor. However, due to precession, the gyroscopes "drift away" from their initial position within a specific time interval. The extent of this "drifting," which leads to disruption of precise attitude control of the spacecraft, is one of the most important characteristics of the instrument. Therefore, the cosmonauts carefully recorded even the slightest "drifting" of Vega from the central field of vision of the sensor during prolonged gyroscopic stabilization of the "Soyuz-9" spacecraft. The high accuracy of the new instrument confirmed the correctness of the design solutions for future navigation systems.

What importance does this have for the future development of space flight technology?

Autonomous navigation aids permit calculation of orbital parameters by instruments and devices on board the spacecraft. In this case, the aid of the ground command monitoring complex is not required.

In practice, ground control may observe the spacecraft only within the zone of radio visibility. During prolonged interplanetary flights, radio transmitters may fail and radio communications may be

disrupted by magnetic storms induced by solar flares. Moreover, target designations from ground control may not always arrive in time. For example, passage of a radio signal from the region of Venus to Earth and return, even with the most favorable position of them, requires more than four minutes.

However, the spacecraft's position in space may be calculated with high precision with the aid of a special onboard sextant. This instrument is used in combination with other navigation aids: solar and star sensors, the cosmonaut's optical sighting device and other systems. During the flight of the "Soyuz-9" spacecraft, the possibility was checked of orientation by other than the most popular stars, Sirius and Canopus, in cosmonautics. Angular distance was also calculated by Arcturus in the constellation Boötes, Deneb in the constellation Cygnus, and certain others. The search for them was carried out at different times of day during passage of the spacecraft through the terminator — the boundary of light and shadow.

After the cosmonaut, by firing the jet thrusters, had "led" the star into the field of vision of the star sensor, the spacecraft was /83
stabilized. Sometimes this position was maintained for an entire orbit, and then the star again "fell" into the star tracker.

Moreover, the cosmonauts calculated their orbital elements by given ground reference points — for example, by the most characteristic lakes and mountain ridges of Africa and South America. In doing so, one cosmonaut usually oriented the spacecraft, observing the Earth with the aid of the optical sighting device, and the other would make the navigational calculations. This method may be useful in the future when a spacecraft is returning to Earth from long interplanetary voyages, as well as during operations on long-duration orbital stations. The navigation experiments indicated the broad possibilities of the orientation and attitude control systems of the "Soyuz-9" spacecraft.

Flight engineer of the "Soyuz-9" spacecraft, V. I. Sevast'yanov, in the orbital compartment.

Investigations of Importance to the National Economy

During the flight, the crew completed an extensive program of scientific investigations of space and carried out a number of interesting experiments and observations of importance to the national economy. Thus,photography of the Earth's surface is of great practical importance for geology. Postflight analysis permits refinement of the main characteristics of mountain formations and possible regions of mineral deposits from them. Photography of sea expanses, carried out in different regions of the spectrum, aids in determination of current propagation, accumulations of zooplankton, and determination of the most promising regions of the seas and oceans for fishing.

Photography of the snow and ice cover establishes water resources, which is very important for agriculture. The results of recording the distribution of the Earth's cloud cover is of no less practical interest. Thus, during this flight multiple investigations of the meteorological characteristics of the atmosphere and western part of the Indian Ocean were conducted for the first time. This region was /84 "inspected" simultaneously from an altitude of more than 600 kilometers by the "Meteor" satellite, by the "Soyuz-9" spacecraft, and by the scientific research vessel "Akademik Shirshov," which carried out soundings of the atmosphere with meteorological sounding balloons.

The investigations will aid more accurate forecasting of the weather phenomena of our planet.

It should be noted that successful completion of the space flight was due to a great extent to the well-coordinated work of the ground command monitoring complex, the flight control center, and

floating scientific monitoring stations, headed by the vessel "Kosmonaut Vladimir Komarov." This flight demonstrated that modern space technology reliably ensures the cosmonauts' performance of a large volume of scientific and practical operations during orbital flights of unprecedented duration.

8. THE FIRST ORBITAL STATION OF LONG DURATION IS IN SPACE /85

"Salyut" Is In Orbit

Completion of the work of the 24th Congress of the CPSU, which noted the prospects for development of our country during the Ninth Five-Year Plan, coincided with a historical date: 10 years ago Soviet citizen Yu. A. Gagarin completed a flight into space in the legendary "Vostok" spacecraft, a flight which opened the way to the stars for mankind.

Only ten years have passed. The space industry is now in the service of the people and contributes to discovery of new secrets of the Universe and to the development of science and the national economy. Space vehicles have become more complex, more roomy, and more modernized. They have been equipped with new apparatus and systems for performing an extensive complex of experiments.

On that day, when people were recalling the exploit of Yu. A. Gagarin and noting 12 April as the Day of Cosmonautics, last-minute preparations for a routine flight were underway at the Baykonur Cosmodrome...

A gradiose structure — a new powerful launch rocket and an object of enormous dimensions, covered by shrouds, is on the launch pad. The engineers call it simply a "payload" or space object. A new envoy to space is hidden behind the shrouds. Who is he?

...On 19 April 1971, the roar of powerful engines again awakens the Kazakh Steppes, covered this time by bright multicolored tulips.

This roar was considerably more powerful than previously, and no wonder: a heavy vehicle about 20 meters in length is being launched into space! /86

And within a short period, Yu. B. Levitan, announcer of All-Union Radio, read the first lines of a new TASS communication: "In accordance with the program for investigation of space, on 19 April 1971 the orbital scientific station 'Salyut' was launched... The purpose of launching the station is to test the design elements of onboard systems and carry out scientific investigations and experiments during space flight."

The long-duration orbital scientific station "Salyut" is taking an examination in space flight. The operation of the onboard systems, units, and scientific equipment is being checked. According to telemetry data, everything is in order.

The orbit is corrected at the calculated time. The station is controlled with the aid of an extensive network of monitoring stations, located throughout the territory of our country. The ships of the USSR Academy of Sciences, the "Morzhovets," "Kegostrov" and "Akademik Sergey Korolev," located in the Atlantic Ocean, also conduct joint operations with the "Salyut" station.

The station is now operating in the automatic mode. But it will soon take on board its first crew. The world is excitedly following the beginning of a new space premiere...

Call Signs are "Granit"

Four days later, on 23 April, a new launch! The "Soyuz-10" spacecraft is injected into the calculated orbit with a crew consisting of well-known space conquerers pilot-cosmonauts of the USSR V. A. Shatalov, A. S. Yeliseyev and a new representative of the cosmonaut detachment, N. N. Rukavishnikov. This is the first manned flight of the new space decade!

The cosmonauts carry out the necessary preparation of the spacecraft for joint experiments with the "Salyut" station, maneuver in orbit and check the systems. "Granit" — "This is 'Zarya.' Over!" — is heard over the loudspeakers in the Computer Coordination Center and in the Flight Control Center.

Thousands of people are taking part in creation of the space object and preparation of it for launch. Part of them in the shops, laboratories and design bureaus are already engaged in a new project — they are preparing new spacecraft. Others began work after the launch — these are the ballistics experts, telemetry, and radio specialists. But all of them are caught up in the excitement and pride in the might of our technology and in the beauty and grandeur of man.

On 24 April 1971, one day after launch, the "Soyuz-10" spacecraft approaches to within 180 meters of the "Salyut" station. The crew then takes over control. Approach, mooring and, finally, docking take place! Moscow time is 4 hours 47 minutes. The flight of the /87
station-spacecraft system continues for 5 hours 30 minutes in docking mode. During this time, the most important operations in checking the onboard systems were performed, the characteristics of orientation and control of the complex were analyzed, and complex technical experiments were carried out. A picture of the "Salyut" station and its individual structural elements is transmitted to Earth with the aid of television cameras. Finally, we see the vehicles separate and "Soyuz-10" moves away from the station.

The scheduled program of experiments has been completed and operations are being carried out in preparation for return of the spacecraft to Earth. Next day, on 25 April at 2 hours 40 minutes, the spacecraft made a soft landing in the calculated region. Specialists of the search group, sports commissars, representatives of the press and friends embrace the crew of "Soyuz-10." The flight has been completed and the program of scheduled investigations has been fulfilled, but the bold experiments with the "Salyut" station will be continued and very soon ...

Into Space Toward the Station

May, 1971. "Salyut" continues its flight. The onboard systems are being checked. Upon command from ground control, the scientific equipment records the situation in near space. By 7 May the station has completed 295 revolutions around the Earth. Within the following days of the week, it will complete another 200 orbits. The parameters on the station are normal: temperature is 15° C and pressure is 920 mm Hg. The station is ready to receive the new envoys of Earth. And the days on Earth are busy ones: the crew of "Soyuz-10" is giving the results of their investigations and impressions to the crew of "Soyuz-11." Processing and analysis of telemetry on the flight of the "Soyuz-10" spacecraft have been completed and preparations are underway for a new launch.

Incidentally, the family of space envoys is ever expanding. Three vehicles — two Soviet and one American — are rushing toward Mars in the year of the great opposition. The "Mars-3" probe carries on board, along with Soviet equipment, French apparatus, prepared according to the program of international cooperation. The mass of the "Mars-2" and "Mars-3" probes is impressive — 4.5 tons!

The Soviet automatic vehicle "Lunokhod-1" continues its work on the Moon. Six months of fruitful work — much more than the specialists calculated. And the lunar roving vehicle continues to move about, its scientific equipment functions faultlessly, and a mass of new and unique data is transmitted! Automatic vehicles have an important future in studying difficult-to-reach regions of the Universe. Economically, automatic vehicles are more advantageous; furthermore, they have a high information content, are reliable, and efficient. The cooperation of man and automatic devices is increasing. There is no conflict here, but rather rational cooperation and intelligent strategy and tactics of investigation and conquest of space.

Spring in space is ending and the hot summer is beginning: new /88
launches and new assault positions.

"Soyuz-11" is flying above the Earth. This occurred on 6 June at 7 hours 55 minutes Moscow time. The new spacecraft was injected into a low orbit. The crew consists of spacecraft commander G. T. Dobrovol'skiy (cosmonaut-24), flight engineer pilot-cosmonaut of the USSR V. N. Volkov and investigator-engineer V. I. Patsayev (cosmonaut-25). The mission of this crew is to go into space to the "Salyut" station for prolonged operations.

A Tour of the "Salyut"

On 7 June 1971 the manned station "Salyut" was created and began to move in a low orbit. At 10 hours 45 minutes Moscow time, the crew of the "Soyuz-11" spacecraft entered the compartment of the scientific station after the vehicles had docked and all systems were checked.

The most important engineering and technical problem of delivering a crew by transport spacecraft to a scientific station — an Earth satellite — was solved for the first time. The cosmonauts entered the station compartment through an internal passage.

Let's take a brief tour of the "Salyut" with them. Before entering the station, it is necessary, while still in the "Soyuz" transport spacecraft, to check the pressurization of the compartments and operation of the onboard systems of the station, the microclimate parameters in the compartments of the docked vehicles, to equalize pressure, open the cover of the sealed hatch connecting them and then enter the transfer compartment. A number of control consoles and part of the scientific astrophysics equipment are located in this compartment. This is one of the living compartments of the station and, therefore, its diameter is quite large, of the order of two meters. The hull with its portholes is pressurized, the interior is covered with decorative materials, and the antennas, solar batteries and scientific instruments are mounted on the outside.

The cosmonauts enter the working compartment through a special hatch. A platform is located beyond the hatch. On it facing the hatch are two cosmonauts in their work seats. There are several

consoles and instrument panels in front of them and command-signalling devices and equipment to the sides. The compartment is located in the center part of the station and is the main compartment. This is essentially a comfortable laboratory, suitable for prolonged scientific investigations in the station and control of it. The cosmonauts can carry out the necessary complex of physical exercises, eat and rest here.

Inside the hull there are water and food supplies in special containers, life support systems, radio instruments, equipment for controlling the complex, an electric power supply, devices for moving about, attachment and physical training of the crew, and scientific and experimental equipment. The compartment is equipped with 12 port-holes with removable equipment for orientation and navigation, photog- /89
raphy, and visual observations. The places for the cosmonauts to work and rest are comfortable. The sleeping arrangement of the station permits the sleeper to strap himself into a comfortable posture. An onboard medicine chest is located in the compartment.

Humidity, temperature, and pressure are maintained at normal levels, which permits the cosmonauts in the work compartment to wear ordinary light overalls without spacesuits. Part of the scientific equipment and the main onboard equipment, powering the station, are installed in this compartment.

A station is located near the equipment compartment for investigating the plasma parameters around the spacecraft. There are also two additional work sites. The antennas and sensors are located outside the work compartment. The equipment compartment is arranged behind the work compartment. It is unpressurized and consists of a supporting skirt on which are located antennas, ion sensors, assemblies of the heat regulating system and the engine compartment, which is linked to the entire system of servomechanisms, permitting maneuvering of the station. The fuel tanks, television cameras for external viewing, and solar battery panels are located in the engine compartment.

The long-duration orbital station "Salyut" is a multipurpose space research laboratory for prolonged investigations and rotation of crews. The scientific equipment and instruments installed in the station make it possible to carry out an extensive complex of astrophysical, physicotechnical and medical-biological experiments, as well as to develop experimental methods of controlling systems of the orbital station.

Externally, "Salyut" looks impressive: there is a cone, on the end of which is the docking unit, then a cylinder two meters in diameter, then expansion of the cylinder to three meters, then expansion to approximately four meters, and, finally a spherical bottom and cone — the fuel tanks, and behind them, the engine. Four solar battery panels, antennas, and equipment are located on the hull. The total length of the station is about 20 meters, and its volume is almost 100 cubic meters.

The mass of the "Soyuz"-"Salyut" system is a record for manned objects in orbit — about 25 tons. Prolonged operation of the base-station is ensured by the large resources for operation of the systems, assemblies, and equipment, especially those which must function continuously.

The grandeur of the "space dwelling," injected into the low orbit of an Earth satellite, is striking. It somewhat resembles a modern submarine. It has the same pressurized compartments, transfer hatches, work sites with the consoles for different equipment, but, of course, the work compartment is more spacious than that in a submarine. The cosmonauts also have at their disposal the compartments of the "Soyuz" transport spacecraft, in which are located part of the scientific research apparatus and equipment. They may also work and rest in these compartments.

Watch in Space

The crew has arrived at the "Salyut" space station and has taken over control of the flight themselves — this exciting news was reported by the newspapers of all countries on the evening of 7 June 1971. What is the program of scientific and technical observations and experiments which awaited completion by the crew of the "Soyuz-11" spacecraft? First, there was thorough checking and testing of the structure, assemblies and onboard systems and equipment of the "Salyut" under conditions of extended flight. The station is new, a first-born of our space industry, and, therefore, like a new aircraft or automobile, everything must be checked: the efficiency of the systems, their controllability, communications with the control center, and much more.

Operation of the service systems, which ensure the operation of the scientific equipment and life support systems, was checked as early as April, when "Salyut" was functioning in the automatic mode. It passed the examination on strength and adherence to specifications successfully — the microclimate parameters in the compartments are normal, the power systems are also normal, and radio and television communications with ground control are excellent.

They may now turn to checking the maneuvering qualities of the docked space system. The first experiments on orientation were performed after docking of the "Soyuz-10" spacecraft. The program has now been expanded: it includes experiments on flight control directly from the station, maneuvering in orbit, and testing of methods and autonomous attitude control facilities and navigation of the station.

Operations on changing the orbit had already begun on the following day. By correcting it, the station is transferred to a higher orbit. The first time, the mooring and attitude control thrusters were fired for this. The crew observed operation of the thrusters: behind the windows of the portholes they observed the flares and flight of bright particles. After changing the perigee — the minimum distance

from Earth — they began to carry out a routine task: the apogee also had to be raised somewhat.

The second correction was made on the following day. "Zarya!" We are reporting: the engines fired for 73 seconds!"

Everything is normal — the station is flying high above the Earth in optimum orbit. Correction of it, obviously, does not occur at once. The complex is easy to control, and it is now necessary to orient the solar battery panels toward the Sun. The cosmonauts also perform this operation manually. The attitude control systems are operating normally.

Preparations for conducting scientific investigations began on the first day that the cosmonauts arrived at "Salyut." But the scientific equipment must first be unpacked, adjusted, and prepared for operation. There are many instruments and various systems. All preparatory operations required almost three days of work by the crew. By this time, stowing of a number of systems of the "Soyuz-11" space- /91 craft had been completed — after all, undocking and return to Earth would not take place anytime soon and, consequently, part of the instruments and equipment of the transport spacecraft are not required at present. Their condition may be subsequently monitored by telemetry data.

The scientific instruments installed in the "Salyut" station permit extensive investigations of the physical processes and phenomena in the atmosphere and space, observation of celestial bodies, investigation of the radiation and micrometeor situation in space, and study of the various types of cosmic radiation.

A wide-angle optical sighting device — a new instrument designed for precise orientation on the Sun and planets — was tested among the experiments conducted in the "Salyut" station. While making navigational measurements, the cosmonauts calculated the orbital parameters of the station with the aid of the onboard computer.

Experiments carried out with the aid of the station's gamma telescope are interesting and full of promise for science. The intensity, angular distribution, and energy spectrum of primary cosmic radiation were studied. Moreover, the crew commander switched on the gamma telescope and monitored its operation, while the flight engineer carried out attitude control and stabilization of the station.

Experiments were performed on investigating the effect of the space environment on the properties of special optical specimens with the aim of developing astronomical telescopes, brought out into space beyond the atmosphere to eliminate interference. Interesting data were obtained as a result of investigating different types of radiation, which barely reach the Earth and which are distorted considerably by the atmosphere.

Investigation of geological and geographical objects on the Earth's surface, various atmospheric formations and the Earth's snow and ice cover is of great practical importance to develop methods for utilizing these data to solve national economic problems.

The Earth is a very convenient object for observations from space. Large areas can be scanned within a very short period of time, and panoramic observations are very easy. Geologists can judge the characteristic features of the structure of Earth's core, oceanographers can observe the water surface and estimate the water resources in the world ocean, icthyologists and fishermen can determine the locations of fish shoals and plankton, and botanists can compile accurate charts of the distribution of vegetation (incidentally, the first such chart was obtained from the photography of the "Zond" probe) from the results of the investigations.

All crew members of the orbital station carried out systematic investigations: they made spectrographs of individual sections of the Earth's surface over the USSR to study natural formations and the water surface, measured the optical characteristics of the atmosphere, /92
photographed various atmospheric formations, and observed the weather

along the flight route. The cosmonauts photographed the cloud cover in the Volga region, and a television survey was simultaneously made of it from the "Meteor" satellite. They made a spectral survey in the region of the Caspian Sea in order to utilize the data in agriculture, land reclamation, geodesy and cartography. Aerial photography of the same regions was carried out simultaneously from aircraft by scientists of the USSR Academy of Sciences and Leningrad University.

Many things came into the field of vision of the astronauts: large burned areas, cyclones and typhoons. And all these are objects for observations and investigations of the cosmonauts. This is not surprising — man on the Earth and in space is now host of the planet and he should be concerned with its present and future fate.

The medical and biological experiments, directed toward further study of the effect of prolonged space flight factors on the human body, and experiments to determine the cosmonauts' ability to perform different operations, and to study their psychological compatibility in closed space were an especially important group of investigations.

Thus began the stage of creating long-functioning orbital stations. Will man live and retain a high level of efficiency under these conditions? How will the process of readaptation proceed upon return to Earth? What measures will have to be taken by physicians and technicians to increase the duration of the crew's stay in the station? We know, for example, that prolonged exposure to weightlessness may lead to a number of serious changes in the human organism. Solution of this problem should proceed both toward increasing the amount of physical training exercises of the cosmonauts and toward creating so-called "artificial gravity" in the future by bringing the force of gravity in the station to levels close to those on Earth. In the latter case, either individual sections or the entire station must be rotated at specific angular velocities. Many other problems must also be solved: problems of the everyday life and hygiene of the crew during flight, feeding, sleep, rest, and creation of closed

ecological systems which provide complete regeneration of the atmosphere and water in the station. Many of the enumerated problems were included in the program of the manned flight of the "Salyut" station!

During the flight of the orbital station, the cosmonauts tested specially created overalls of various designs, permitting them to tolerate weightlessness. Such overalls permit the cosmonauts' bodies and their osteomuscular systems to retain their accustomed Earth load. Due to this, as scientists assume, calcium depletion, which weakens /93
the bone system and which occurs during weightlessness, may be prevented. The cosmonauts approved the new overall designs and stated that they were comfortable and suitable for continuous wear.

The program of medical and biological investigations, conducted by the first crew of the "Salyut," was extensive. Data on the radiation safety of space flights and problems of dosimetric monitoring were studied, investigations were carried out on the state of the cardiovascular system, functional samples of expiration, gaseous metabolism, and energy expenditures were taken, and the light and contrast sensitivity of the eyes and the psychophysiological state of the cosmonauts were investigated.

After completing the large and complex volume of prolonged scientific experiments on board the world's first long-duration orbital station "Salyut," its first crew died tragically upon return to Earth in the "Soyuz-11" transport spacecraft. Spacecraft of this type had made repeated space flights and had safely returned cosmonauts to Earth. However, it is almost impossible to exclude an accident when testing new technology.

The heroic exploits of the courageous conquerers of space, G. T. Dobrovol'skiy, V. N. Volkov and V. I. Patsayev will be permanently entered in this history of cosmonautics. The first crew of the "Salyut"

completed the extensive program of scientific investigations to the full extent and with great success and fulfilled the mission of their Fatherland with honor.

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The efforts of Soviet scientists, designers, workers, and courageous experimenters created the world's first large building in an Earth satellite orbit. People were able to work beyond the confines of the atmosphere. This building is that of all mankind. Transport spacecraft will be able to provide rotation of station crews, to ferry the necessary equipment, and food and water supplies to them, and to replace instruments and equipment which break down.

The excellent space laboratories are attractive to scientists. There will be more and more orbital stations. And, D. Dennis, President of the French National Space Center, is undoubtedly correct when he said in the name of all scientists of many countries: "An important step forward has been taken, which indicates a qualitatively new phase in the study and investigation of space... Creation of the first orbital station demonstrates that what we only recently dreamed about is becoming reality..."

Yes, dreams do come true!

9. THE PRINCIPAL METHODS OF DEVELOPING ORBITAL STATIONS /94

Automatic or Manned Stations?

Various designs, sometimes very exotic, of future space stations are often found in the current literature. When one becomes familiar with their description, many questions arise. Why does mankind need manned space stations? Cannot all space research be conducted by automatic vehicles alone? What possibilities do manned space stations open for scientists? Is it not possible to manage space research without the direct participation of man?

The appearance of these questions is explained by the rapid development of automatics and telemechanics, improvement of automatic control systems, means of control and telemetry, and by progress in the field of programming and computing devices.

In the course of technical progress, individual human functions — reception, storage, transmission, and processing of information — are more and more being handed over to automatic machines.

Two organically related aspects must be taken into account when evaluating the role of man in space research. On the one hand, there is the ongoing process of automatic machines replacing man, and in connection with this the range of problems which a certain system is capable of solving. On the other hand, the greater the number of automatic machines introduced into the control process and the broader the range of problems solved by them, the more necessary it becomes /95
to integrate their operation, i.e., the relative role of man increases.

It should be noted that there are serious arguments among the proponents of pure automation. They feel that scientific research, for example, study of the parameters of near space, may be accomplished (and is being accomplished) with the aid of automatic Earth satellites, which have proved themselves as reliable facilities for scientific research in space. As automatic aids for observation and telemetry are further developed, more and more complex investigations can be carried out without the direct participation of man. And what is especially important, automatic equipment can be employed successfully in those cases, when the participation of man in an experiment is impossible or difficult. For example, study of such planets as Saturn, Uranus and Neptune may already be begun with the aid of automatic vehicles, while at the same time, expeditionary flights by man to them with subsequent landing on their surface and take-off are impossible in the foreseeable future. The gravitational forces on these planets are many times greater than those on Earth.

Investigations of the Moon, Mars and Venus with the aid of automatic stations have already permitted much new information about them to be obtained. Moreover, the cost of launching automatic vehicles is considerably less than that of manned flights.

Participation of man in space flights should be regarded as feasible only when it is necessary and justified.

Another argument of the proponents of replacing man by automatic machines is the complexity of providing life support for man exposed to the effects of space, which hinders the possibility of a prolonged stay of man in flight.

Undoubtedly, the requirement for life support systems for man on board a space station reduces the space available for scientific equipment by those weights and volumes, but at the same time, because of the presence of man, some systems (for example, the attitude control system of stations) may be simplified, and this increases the possibility of installing additional equipment. And it is quite obvious that we can only gain from the presence of man as the weight of space stations in orbit and the time of their active functioning increase, with expansion of the complex of problems solved by them.

Man is capable of rapidly analyzing a developing situation, actively interfering in it and taking the necessary actions. Whereas an automatic machine sometimes wins in the speed of "thinking," it can hardly be compared to man in the flexibility and completeness of "thought." The human brain has the ability to generalize, which no automatic machine yet has. Man can carry out rapid and most precise analysis and synthesis of information and select from an enormous /96
amount of diverse information that which he requires at a given moment.

The functions of man on board a space station may be varied. Besides observations and transmission of information to Earth, man is also entrusted with the function of monitoring the performance of the flight, maintenance of the complex onboard equipment, exercising of manual flight control and landing on Earth in case of failure of automatic systems and other tasks.

Thus, during the flights of the "Soyuz" spacecraft, the cosmonauts not only conducted scientific and technical investigations, maintained communication with Earth and monitored the instrument readings, they also oriented the spacecraft toward the Sun with the aid of the manual control system to ensure optimum power supplies for the onboard instruments.

Approach of the "Soyuz-4" and "Soyuz-5" spacecraft proceeded automatically within the range of the search and guidance radar. Further approach and docking were performed manually by the cosmonauts. Thus, both man and automatic machines actively participated in the creation of the first experimental station.

Participation of man in space research increases the efficiency of fulfilling the task due to utilization of his reactions, ability to analyze information, to draw conclusions, and to make decisions in unexpected situations. The ability of man to select the solution required from among several possible versions simplifies certain components of onboard equipment and their principles of operation.

The role of man in monitoring equipment consists of "detecting manfunctions," i.e., man, by using the display systems, should be able to detect and localize the failed component.

Man usually combines a number of functions, performing them either simultaneously or in sequence. Man is capable of changing the methods of controlling a system in case some previously unforeseen circumstances occur.

An automatic machine has its own, rather ponderable advantages: it is not subject to fatigue, irritability, uncertainty, fear and similar emotions. But only man possesses will, reason, and creativity. These qualities were clearly demonstrated by our cosmonauts and ensured magnificent performance of the complete flight program, which included such complex phases as docking, transfer from spacecraft to spacecraft, controlled descent, etc. Automatic machines do not exclude man from

the sphere of creative activity, and we are concerned here only with the optimum, most advantageous combination of properties and qualities of man and machine for best performance of the assigned task.

The necessity for man's presence in space should not be understood as his presence in every space vehicle or during every scientific investigation. Creation of manned stations does not exclude, /97 and even assumes, the presence of automatic laboratories during orbits around the Earth. It may be that they will be serviced by cosmonauts, and crew members of orbital stations, using "Soyuz" type spacecraft, will visit them periodically for inspection, readjustment, replacement, or repair of failed equipment and to retrieve information.

The necessity of implementing manned flight should be justified and dictated primarily by the extent and the program of operations, rather than by a desire for an external effect or emotional impressions. There are still many problems in cosmonautics which man can solve, but he should not have to do everything himself.

Design Characteristics of Future Space Stations

One naturally assumes that, following the first long-duration experimental space station, new stations of various weight, dimensions, and designation with an extended lifetime will appear in low orbits in the near future. Let's try to imagine what kind of stations these will be and what will be their principal design characteristics.

The method of assembly determines the design of a space station. Two methods are more probable.

On the ground. In this case, the station is completely assembled on the ground and launched into orbit ready to perform its tasks immediately.

In orbit. In this case, the station is assembled in orbit from several individual units, sections, components or spacecraft, which are orbited in sequence by several launch rockets. The station is

ready to perform its tasks after final assembly. Thus, a station of any weight, dimensions and type may be created.

In the first case, the crew may be either injected into orbit simultaneously with the station or delivered there separately by another spacecraft. In the second case, the station may be assembled automatically or by a special assembly-repair team. This team completes assembly and checks the assembled station. Afterwards, special spacecraft deliver the crew to the station and the assembly-repair team may return to Earth in the same spacecraft.

Both methods of creating orbital stations have their advantages and disadvantages.

Some losses in payload weight are inevitable during orbital assembly, because each unit or section from which the space station is assembled must have its own onboard systems and engines for approach.

These losses are increased if lightweight units or sections are used in assembly of a large station. However, orbital assembly of a station permits the creation of one of any required weight or dimensions using existing launch rockets for orbit injection of individual units, whereas in ground assembly the weight and dimensions of the station are limited by the thrust output of the launch rocket.

Moreover, unsuccessful launch of one of the units does not mean an interruption of the entire program, and launch may be repeated, whereas an unsuccessful launch of a station assembled on the ground may postpone orbiting of the station for a prolonged period.

It is obvious that so-called small stations will be created by the method of assembly on the ground. The basis of creating large stations, on the other hand, is the method of orbital assembly.

What then are "small" and "large" stations?

These concepts are, of course, arbitrary, and we will understand them henceforth as the following.

Small stations, weighing from several tons to several tens of tons, are intended for solving more important scientific and national economic problems, which are as similar as possible in nature. The active lifetime of such stations will obviously not exceed several months or a year, and they will be more maneuverable than large stations.

Large stations, weighing hundreds of tons, will be designed for solving a broad range of scientific and national economic problems. Stations of this type will have a prolonged active lifetime (up to several years or even tens of years), which will require the latest means for delivery of the crew, equipment and material and technical supplies to the station. The characteristic feature of these stations is that an entire complex of different scientific and national economic problems may be solved on them.

What will be the external and internal appearance of future space stations?

The external appearance of the station will depend mainly on the method of assembly. By using orbital docking, stations of any weight, dimensions and configurations may be created, with any number of compartments. The compartments from which the space stations will be assembled will obviously be spherical or cylindrical in shape. Such shapes give the greatest weight in a given volume and are convenient for assembly and configuration of the equipment inside them. A station assembled from such sections may have any configuration: cylindrical, spherical, in the form of a hub with spokes, dumbbell, toroidal, etc.

Depending on its purpose, the station will consist of different compartments. However, both small and large stations will apparently contain the basic compartments found in "Soyuz" type spacecraft.

The command compartment (the cosmonauts' cabin in the "Soyuz" spacecraft) is a pressurized compartment, designed for disposition of the cosmonauts' work sites and control consoles of the onboard equipment of the station. This same compartment may serve to return the cosmonauts to Earth, depending on its design. /99

The laboratory compartment is a pressurized compartment which contains the equipment required to carry out experiments and scientific investigations, as well as part of the service equipment.

The orbital compartment is a pressurized compartment, designed for crew members off duty. This compartment will contain everything necessary for rest and preparation and eating of food. The food stores and life support equipment will also be located here. The compartment will be equipped with a special hatch or airlock chamber for the cosmonauts to exit into open space (such as, for example, that on the "Voskhod" spacecraft) and for performing external operations, experiments and scientific investigations outside the spacecraft and transfer of the crew and cargo from the transport spacecraft to the station.

The instrument-equipment compartment is designed for disposition of the main part of the service equipment, onboard systems, power sources, fuel supplies for the attitude orientation, stabilization, approach, and correction thrusters.

The command, laboratory, and orbital compartments will be equipped with hatches for transfer from one compartment to another. Of course, small stations may consist of other compartments. All this depends on their specific purpose.

When considering the possible configurations of large stations, preference is usually given to cylindrical or toroidal shapes. However, these shapes have both advantages and disadvantages. Thus, for example, a cylinder, yielding an ideal geometrical and compositional configuration of a station, has considerable disadvantages for the creation of artificial gravity by rotation about the main

axis of inertia. The station becomes unreliable when the stabilization system fails, and the motions of the crew lead to oscillations of the station. But such stations easily fit the general contour of the launch rocket, which cannot be said of toroidal stations. However, the latter are very convenient for creating artificial gravity. Stations of toroidal shape will be assembled in orbit.

Depending on the type of station, the number of crew members may vary and may even reach several tens of people. The composition of the crew will depend on the purpose of the station and may consist of pilot-cosmonauts and engineers, who control the flight and perform maintenance, engineer-investigators, physicians, biologists, physicists, astronomers and scientists of other specialties.

The orbital parameters of the station are determined by the problems which it will solve, as well as by such factors as fuel /100 expenditures for orbital correction, ensuring reliable and qualitative radio and television communication of the station with the Earth, the economy of transportation communications between the station and Earth, etc.

Thus, for example, low-altitude orbits considerably reduce the cost of servicing a station, since the lower the orbit, the greater the payload that can be delivered to the station, using launch rockets of identical thrust.

Orbital altitude also affects the weight of the station itself, because a less powerful rocket may deliver compartments of greater weight, from which the station will be assembled, to low orbits.

As an example, let's try to imagine one of the possible designs of a future space station. The station has the shape of a "wheel" in orbit, consisting of a 12 to 16-angle "rim," a "hub," and 6 to 8 "spokes," connecting the rim and hub. Such a station may be assembled from cylindrical compartments, which are first orbited. The station is divided into compartments isolated from each other. The compartments are linked together by sealed hatches. Each compartment may be

equipped with autonomous life-support systems. This increases the safety of the station crew members. Since the station is designed for a prolonged lifetime, artificial gravity is created on it by slow rotation. This has a favorable effect on the crew's health, and the crew members may stay in the station for prolonged periods.

The rim compartments are designed for living and working quarters. Some compartments are designed for sleep, rest, and eating by the crew members. They contain sleeping bunks, a dining area, lounge, etc. In short, the conditions in these compartments will hardly differ from those on Earth.

Other rim compartments will be used to control the station and to conduct experiments and investigations. They will contain everything necessary for normal work of the crew.

The working and living compartments are connected to the spokes, which are in turn connected to the hub. The spoke compartments contain the service and scientific equipment, storage areas for disposition of the life support system supplies, spare equipment, fuel for the engines, etc.

The hub will serve as a dock for transport spacecraft and as a laboratory, in which experiments and scientific investigations may be conducted under weightlessness.

Transport spacecraft will rotate the crew, deliver components for the life support system, fuel for the correction and stabilization thrusters, new equipment for the service systems, scientific equip- /101
ment, etc. These same spacecraft will return the crew, completing its shift, to Earth, and the equipment and materials of scientific investigations, which must be returned to Earth.

The crew of such a station may reach several tens of persons, depending on the tasks being resolved. The crew will be delivered to the station gradually, after the station has been assembled in

orbit. Special cosmonaut-assemblers will assemble the station. The transport spacecraft, the required number of which will be docked to the station at all times, will be used to evaucate the crew in case of an emergency.

It is quite possible that the crews of these stations will consist of representatives from different countries, who will set up joint experiments, since the problems of study and conquest of space and celestial bodies are even now becoming more and more gradiose, concerning the interests of all countries, and space research and technology are more and more entering the life of mankind, are beginning to play an ever greater role in economics, and have an ever greater effect on the development of all human culture, in addition to science and technology.

Problems of international cooperation in creation of complex space systems have already been discussed in detail at the International COSPAR Conference in May 1970.

The Problem of Servicing Space Stations

The problem of ensuring the prolonged functioning of manned space stations is one of the main ones. The stations should remain in orbit for one or several years. Theoretically, a large orbital station may be returned to Earth and again injected into orbit, but this is very difficult in practice (powerful launch rockets are required) and economically unfeasible. Therefore, stations with a prolonged active lifetime should be in orbit permanently. However, the creation of adequate reserves (components for the life support system, fuel, spare parts and assemblies for the service equipment, scientific equipment, etc.) on board orbital stations for autonomous operation for a prolonged period is practically impossible. Moreover, the station crew must be rotated periodically.

Regular supply of the station is an extremely important problem. So-called transport spacecraft, capable of extensive maneuvering, will be created for solving this problem.

Transport spacecraft will be launched periodically from Earth-based cosmodromes, will approach the stations and dock with them. The external configurations of transport spacecraft are determined to a considerable degree by these requirements.

Different types of external shape of transport spacecraft are possible, for example:

wingless spacecraft, utilizing the lifting force created by their hull upon reentry into the Earth's atmosphere;

winged spacecraft, designed for reentry at high speeds, but having good aerodynamic characteristics when gliding at low speeds, i.e., space aircraft.

These spacecraft will be capable of maneuvering at hypersonic speeds.

The main advantage of a high lift-to-drag ratio at hypersonic speeds is the broad capability for horizontal maneuvering during reentry, and in individual cases, during take-off, and the capability of repeated use of the spacecraft, significantly reducing the cost of supply and servicing of space stations.

Development of a transport spacecraft involves a number of peculiarities, regardless of the spacecraft category.

For instance, the required number of cargos delivered is determined by the purpose of the station being serviced, by the number of its crew and by its type of onboard systems, in particular, life support and power supply systems.

The transport spacecraft and the frequency with which it is launched have different effects on the entire program of material and technical supply. Launch frequency is affected by the number of crew members at the station, the duration of their stay in orbit (periodicity of crew rotation), requirement for replenishing consumables and delivery of new equipment, and by the transport spacecraft lifting power.

Problems, related to prolonged functioning of manned orbital stations and automatic vehicles, may be solved with the aid of transport spacecraft.

Transport spacecraft may be utilized for:

delivery of crew members to orbital stations and return to Earth;

rescue of station crew members and crews of other manned space vehicles during emergencies in orbit;

resupply of stations with components of life support and vital systems, various types of equipment, materials, fuel, etc., which they consume during their functioning;

delivery of experimental equipment to the station for conducting investigations under conditions of space and return of the necessary experimental and scientific equipment from the space stations to Earth;

repair and preventive maintenance inspections of the automatic space equipment in orbit — a type of "resuscitation" of them (restoration of their functioning);

training the crews of flying vehicles.

These tasks place the following requirements on transport systems:

economy in operation of the transport spacecraft (ensuring return with repeated use); /103

providing operations for rendezvous in orbit, docking and delivery of cargos;

extensive maneuverability for rendezvous and docking with orbital space stations;

capability of reentry within a wide corridor and landing in the given region;

high reliability, i.e., the capability of emergency rescue during all stages of flight;

providing all necessary conditions for the presence of man;

continuous readiness for return to Earth.

Even now the "Soyuz" spacecraft meets many of the requirements placed on transport spacecraft. Thus, for example, the "Soyuz" spacecraft may:

deliver the crews of manned spacecraft to Earth;

rescue cosmonauts during emergencies;

resupply manned space stations with the necessary cargoes and experimental and scientific equipment;

rendezvous, approach, moor and dock in orbit;

land in the given region with high precision.

Thus, we can confidently say that solution of the problem of servicing space stations has begun to be successfully solved in the Soviet Union, and that the world's first prototype of an orbital station and transport spacecraft has been created.

Space Stations in the Service of Man

Manned orbital stations permit the solution of an extensive complex of scientific problems and those of national economic importance, related to the further conquest of space.

Many problems have already been solved by the "Vostok" and "Voskhod" spacecraft, and many are being solved with the aid of the "Soyuz" spacecraft. But the prospects, opened up with the appearance of orbital stations, are difficult to overestimate.

Let us take astronomy, for example. Rocket technology opened new possibilities for studying the planets, stellar worlds, and cosmic space.

Astronomy has already undergone several revolutions, and its history may be divided into three stages. The first stage is the study of celestial bodies with the aid of optical facilities (field glasses, telescopes, etc.). The second is the "era of radio astronomy," and the third is the creation of a space station, opening the way to locating astronomical instruments outside the Earth's atmosphere.

The atmosphere placed several barriers before scientists, which could not be overcome on Earth. /104

Space is filled with electromagnetic waves of all frequencies. Each one carries its own type of information about the section of the universe where it was born. But only an insignificant part of radio waves penetrate the atmosphere and reach the Earth. Some are repelled by radiation belts, some are absorbed by the atmosphere, others are scattered, etc.

The atmosphere not only conceals many things from scientists, it constantly attempts to beguile them, even in the small portion which they manage to see through it. It makes the stars twinkle, but the cosmonauts see that the brilliant points of the stars glow steadily.

The air of the atmosphere circulates continuously and is mixed with the numerous particles in it. And, therefore, astronomers attempt to take their telescopes high upon mountains in order to eliminate somewhat the effects of the atmosphere and its turbulence.

The processes taking place in the universe, of great interest to astronomers, reveal themselves in the ultraviolet, infrared or X-ray portions of the spectrum, which are completely absorbed by the atmosphere.

We will finally be able to carry out observations of the universe in the ultraviolet band. This means that we will find out much about blue stars and white dwarfs, and, possibly, will be able to guess the origin of the energy processes taking place in them.

Moreover, it may be possible to reveal the nature of such puzzling phenomena, apparently related to our Earth, as counterglow — the oval light spot on the background of the night sky on the side opposite the Sun, as well as to determine whether the Earth is surrounded by a cosmic dust cloud. It may be possible to determine the relationship between zodiacal light and the outer solar corona, it may be possible to collect cosmic material, which fills the solar system, and to determine its physical properties.

A study of comets would be of special interest. Comets are those bodies which link us to interstellar space. They may exist in it for indefinitely long periods, but break up rapidly upon entering the solar system. Study of the properties of comet nuclei, composition of comets, and the organic compounds contained in them are of enormous interest for the development of astronomy. This will finally lead to an understanding of the properties of interstellar clouds, from which the planets are formed and from which are created the preliminary conditions for the origin of life.

A space observatory will have access to the study of radiation at all wavelengths, and therefore, it will be possible to study objects of the most diverse nature, which exist in space and which are barely or almost completely unknown: sources which emit gamma- and X-rays, as is inherent, for example, to neutron stars, as well as sources with a negligible surface temperature — black dwarfs, which /105
are abundant in our Galaxy and, possibly, adjacent to the solar system.

Study of quasars and pulsars will throw additional light on the solution of the problem of the origin of the universe as a whole. There is no doubt that the materials, obtained in a space observatory, will reveal many secrets of the universe.

Astronomical instruments are usually unique and, therefore, expensive. They are designed for prolonged operation: discovery of new principles in the world of celestial bodies requires prolonged systematic observation of not just one, but often of many objects of the same type. However, even the most modern apparatus require preventive maintenance, adjustment, and servicing.

Manned orbital astronomical observatories, whose personnel may be rotated from time to time, are the ideal solution to the problem of efficient and rational use of expensive equipment.

No less important is the role of man as the investigator in performing scientific experiments. Considerable changes in the program of observations, which could not be previously predicted, may be required during astronomical observations in space. Novae and supernovae flares, discovery of a previously unknown body, unexpected intensive solar flares, unusual forms of protuberances, ejection of a gaseous jet from a star and many other "puzzling" phenomena, which occur unexpectedly in celestial bodies and which are usually short-lived, and sometimes, simply unique — all this is valuable material for scientific research. In such cases, man should act decisively, analyze the situation quickly, change, if possible, the program of observations, and also do everything possible to obtain the maximum amount of data with the aid of available instruments.

It will finally be possible to free the scientific instruments in an orbital station from the interfering "filter" of the atmosphere, which absorbs a considerable portion of the radiation spectrum coming from the planets, the Sun, stars and galaxies.

Physicists will have an excellent laboratory — the ideal vacuum of space and all the components of cosmic radiation.

With the creation of orbital stations, geophysics and physics of the atmosphere will have the opportunity of conducting prolonged investigations regularly and on a global scale.

It will be interesting to conduct extensive medical and biological investigations on people, animals, and plants in space stations under conditions of prolonged exposure to the space environment. All this is necessary for man to fly to other planets and to improve methods of selection and training of cosmonauts. It does not rule out the /106
possibility that weightlessness will be useful in treating certain human diseases.

The different instruments installed in orbital stations will be able to solve national economic problems. In the same way as meteorological satellites monitor the weather on a global scale, many problems of practical importance can be solved with the aid of orbital stations. It is difficult at present to determine the potential possibilities of orbital stations, and it is impossible to enumerate the problems of the near future, which may be solved with their aid by science and technology.

However, it is quite obvious that orbital stations will contribute greatly to the future progress of mankind.

The Bridge to the Future Is Being Erected Today

The achievements in the conquest of space and the flights of the cosmonauts have greatly ceased to be sensational, and are becoming somewhat routine.

Actually, after the creation of an experimental orbital station, simultaneous group flight of three spacecraft of the "Soyuz" series, photography of Mars, obtained with the aid of the "Mariner" automatic probe, direct investigation of the atmosphere and surface of Venus and, finally, the flight of the American astronauts to the Moon and the triumphant flights of the "Luna-16" and "Luna-17" automatic probes, it seems that there remains no task in the conquest of space which would capture the total attention of the public. Now, if the cosmonauts were to fly for years and far far away, let's say to Mars, to the rings of Saturn or to the moons of Jupiter, this would apparently again capture the imagination of Earthlings.

Nevertheless, is not such a tone in evaluating the current level of the conquest of space too prosaic? Could people really imagine 200, 100 and even 30 years ago what kinds of events would excite the world in the 1960's and 1970's? We have reached the point about which our ancestors dreamed, creating legends and tales about flights in the sky, to the Moon and to the planets. The actual events have surpassed

even the most daring predictions, which only yesterday seemed impossible. Man, armed with the achievements of science, technology, economics and culture, is transforming the face of our planet, understanding the secrets of the universe, the microworld, and of living matter, and is acquiring new types of energy.

Manned flights have opened up extensive opportunities. They have yielded unique scientific information about near space. Man has walked on the Moon. Preparations are underway for more complex and prolonged flights. Automatic vehicles (they already number over a thousand) have become reliable assistants of man in understanding the universe.

Space research has laid the basis for new achievements in the most diverse fields of human knowledge. Within an unprecedented short period, cosmonautics has become one of the main levers of /107 scientific and technical progress. A multiple approach to problem solving, use of the latest achievements of science and technology and a high level of automation are inherent to it.

The workers, designers, technicians, engineers, scientists, and pilot-cosmonauts, who are creating space vehicles and who are implementing with their aid a gradiose program of investigation and conquest of space, have made a considerable contribution to the labor exploits of our people.

Space itself is a gigantic, inexhaustable, infinitely diverse laboratory, created by nature. Such sciences as physics, chemistry, astronomy, biology, medicine and many others, on whose development depends the growth of the productive forces of society and its progress, require information from space to an ever greater extent.

The contribution of cosmonautics to the development of machine building, electronics, study of materials, power engineering and computer technology is considerable.

A great deal of practical experience on the creation and operation of the most diverse highly efficient space facilities has been accumulated, and a powerful scientific and industrial base has been created in our country — the forefather of theoretical and practical cosmonautics, a country which plays the leading role in the conquest of space and which is making a significant contribution to world cosmonautics.

The new technology, new instruments and assemblies, created for satellites, automatic interplanetary stations and spacecraft, are being effectively utilized in the day-to-day practice of enterprises, which manufacture ordinary "Earth" products. For example, one of the most important problems faced by industry in constructing rockets was the creation of new materials, capable of tolerating superlow and superhigh temperatures and resistant to variable loads and vibrations. Such materials were created, and have become widely used.

Many metallurgical processes (for example, bonding of stainless steel and aluminum alloys and welding of aluminim alloys developed for space rocket technology) are finding broad application in other branches of industry. And the industrial equipment and accessories, developed for forming the large components of rocket hulls, are being used in shipbuilding.

Limitation of the weight and size of instruments — a necessary condition for successful investigations in space — had a significant effect on progress in the field of microminiaturization of technical facilities in general.

The unusual operating conditions during space flight, the unique nature of the problems solved, and the requirements for high reliability led to the fact that space rocket complexes became one of the most complex and perfect types of technology. At the same time, organization itself of space research and the solution of a number of /108
problems related to these investigations, are having and will continue to have a considerable effect on the overall level of development of technology and are stimulating this development.

Everyone knows that the Soviet space program is distinguished by a structured aspect and strict sequence in completing specific stages. We go from one important stage to another, concerning ourselves with exhaustive preparation and reliable support of each new step. The step-by-step complication of the tasks performed and, as data are accumulated, the desire to switch from single preliminary experiments to extensive multiple investigations can be clearly followed.

At present, three main fields for application of space vehicles may be rather confidently distinguished — near space, the Moon and circumlunar space, and Venus and Mars.

Near space is the main arena of systematic scientific research and national economic experiments with the aid of automatic vehicles and manned spacecraft. It is here that specialized systems of automatic vehicles are formulated for national economic and scientific purposes. It is here that manned orbital stations will be created in the future and will begin to function, and it is here that future launches of expeditions to Mars, Venus and other planets of the solar system will be possible in the future.

Artificial Earth satellites are serving man even today. Satellites of national economic importance are operating successfully in low orbits for communications and meteorology. The "Orbita" communication system, which employs "Molniya-1" artificial Earth satellites and which is designed for the relay of television programs and long-range telephone and telegraph communications, has already recovered its production costs. Moverover, due to implementation of this system, it is no longer necessary to erect more than 15,000 kilometers of overhead radio relay lines.

We are also obtaining much valuable data from the "Meteor" meteorological satellite system.

The "Kosmos" series of satellites, equipped with different apparatus, are fulfilling an extensive program of diverse scientific investigations. The number of satellites in this series is already approaching 500.

The use of satellites for navigation and geodesy is of great importance for science and technology, transportation and construction. In the near future, such systems will enter regular service in maritime and air traffic control, in laying traverses of intercontinental power transmission lines and petroleum pipelines, and in selecting and surveying the locations of new industrial and residential construction. A new branch of utilizing satellite technology /109 — direct accumulation of data for the fishing industry, water and forest management, agriculture and geology to determine the Earth's natural resources (including the world ocean) and monitoring the rationale of their exploitation — will acquire a special role. Both automatic and manned spacecraft will be employed for these purposes.

It is no longer so fantastic to imagine launching of entire industrial-technical installations into near space. Let's say that it is very difficult to create a high vacuum on Earth, powerful radiation, superlow temperatures or intense magnetic fields. An orbital station is an ideal place where all these conditions are present in combined form. They provide the possibility of developing essentially new technology of many branches of industrial production. In the more distant future, we will apparently be forced to take numerous power installation beyond the confines of the Earth. Otherwise, their operation, which involves release of heat into the surrounding environment, will ultimately lead to an undesirable increase in the temperature of the Earth's surface.

We may assume that artificial satellites will become more specialized and will permit a deeper study of certain processes. At the same time, the service equipment — heat regulating systems, telemetry and radio equipment — will be standardized to a greater extent and will be designed to function for many years. If necessary, specialized systems may be created from this automatic apparatus. The cost of automatic stations and launch rockets will decrease significantly in the future, their launches will make a greater contribution to science and the national economy, and they will yield a discernible saving.

Manned spacecraft and orbital stations, on the contrary, will be more universal and will permit extensive scientific investigations and experiments during flight. Essentially, entire "institutes" will function in orbit. This will permit technical experiments and flight tests of ever more complex circumterrestrial stations and spacecraft, designed for flights to the planets of the solar system.

In a number of cases, heavy automatic multi-purpose satellites will be employed for systematic investigations in space. Equipment, which will be able to function for a prolonged period, should be created for these satellites.

International cooperation will acquire a special role in the conquest of space. Even now the USSR is successfully cooperating with the Socialist countries and France. We hope that an even greater number of countries will join forces in the future. This will considerably expand the front of investigations and rational balancing /110
of expenditures for cosmonautics.

The Moon and circumlunar space in the current Soviet space program is a kind of scientific and technical "test range," where a diverse program of scientific investigations is being carried out and where exhaustive checks are being made on the correctness of the engineering solutions and efficiency of designs and systems under conditions of sharp temperature drops, vacuum, and weak gravitation. Stationary and mobile automatic facilities permit a study of the physical and chemical characteristics of the Moon and circumlunar space. They expand our concepts about the origin and structure of the universe. They operate successfully on the Moon, and are providing scientists and engineers with practical knowledge and necessary experience for creation of new automatic machines.

Venus and Mars are the nearest planets, neighbors of Earth. Like the Moon, they are the objects of study with the aid of space vehicles. These investigations yield unique data, which even the latest Earth-based optical and radio astronomical facilities are

unable to provide. Venus and Mars are unique targets for modern space technology. Automatic interplanetary probes have already been launched toward them. Scientific and technical investigations are being conducted on trajectories, measured in tens of millions of miles, and near the planets. During prolonged flights at great distances from the Earth, the onboard and ground-based facilities for radio control and telemetry, operation of scientific and service equipment, which is affected by the real factors of interplanetary flight, are checked exhaustively and complex ballistics calculations are made. As in a study of the Moon, a foundation is being laid for more complex space flights in the future.

Scientists and engineers are designing new automatic vehicles which will replace current ones within a few years. In the near future, automatic vehicles will begin a study of Saturn, Jupiter and other planets, even to the most distant planet from us, Pluto, in addition to Venus and Mars. Exceptionally broad possibilities for using automatic vehicles open up in the study of small celestial bodies: comets, asteroids, satellites of planets, as well as the remote regions of the solar system, where man cannot yet go. And it is no accident that automatic vehicles are being given an important role in the current Soviet space program, because they are tens of times more inexpensive than manned vehicles, are highly reliable, and transmit data from inaccessible regions. Manned flights in both circumterrestrial space and to the Moon and planets will be undertaken in lesser numbers in relation to automatic vehicles, as required.

Recently different circles of the public, journalists and specialists in the West, have been studying Soviet space research /111 more intently. Its clearness of thought and logical development are noted. The purposeful development of the space program may be followed by the example of 1970. In 1970, the Soviet Union continued its systematic conquest of space in the interests of science, the national economy and for the welfare of the Soviet people — the builders of communism. This was a year of a renowned anniversary — the 100th year from the birth of the founder of the Party and of our state,

V. I. Lenin — a year, which concluded the five-year plan, a year of preparation for the 24th Congress of the CPSU. It was one of importance and reflection for Soviet cosmonautics. More than 85 space vehicles were launched during the year. These were the satellites of the "Kosmos," "Molniya," "Meteor," and "Interkosmos" series, the "Soyuz-9" manned spacecraft, the "Zond-8,""Luna-16," and "Luna-17" automatic probes, the "Venera-7" interplanetary probe and the "Vertikal'-1" rocket astrophysical observatory and geophysical rocket.

During the course of the Soviet experiments, essentially new types of space facilities were approved, technical systems and equipment were tested, a search was conducted for new methods of scientific research and data transmission, and the main problems on which future prolonged flights of man depend were solved.

We recall, for example, the historic flight of the "Luna-16" probe, which returned to Earth with samples of lunar rocks. The successful flight of this probe was a new phase in the development of space automation. The flight of the "Luna-16" probe opens prospects for investigations of planets with the aid of automatic vehicles, which obtain not only the required information, but return it to Earth. How can we not recall the analysis of the flight of the "Luna-16" probe, given by Professor Bernard Lovell, director of the Jordrell Bank Observatory: "The task accomplished by 'Luna-16' is a real revolution in the conquest of space... I am confident that 'Luna-16' will open up possibilities even during this decade to again take samples of rock, in particular on Mars, with the aid of automatic vehicles, In short, a new page has been opened in interplanetary communication and research."

And what about the flight of the "Luna-17" probe?

On 17 November, the vehicle delivered to the region of the Sea of Rains the automatic vehicle "Lunokhod-1" — the world's first mobile automatic space vehicle, which completed an extensive program of scientific and technical investigations in various regions of the lunar surface, and which opened up new possibilities.

The instruments for determining the physiocomechanical properties and chemical composition of the lunar soil, installed on the lunar roving vehicle, permitted experiments at different points over the route of its travel. Astrophysical observations were carried out with the aid of an X-ray telescope on the lunar roving vehicle. We know that the stars of galaxies and other astronomical objects emit powerful X-rays, caused by the superhigh temperatures of the stars and the unusual and transient processes in development of whole galaxies. Observations of such emissions are impossible from Earth, because the Earth's atmosphere is essentially opaque to this type of radiation. Observations from the Moon, which is devoid of an atmosphere, may provide much new data unknown to science.

"Lunokhod-1" also has a laser reflector, manufactured in cooperation with French specialists. This device permits the calculation of the distance from the Earth to the Moon with an accuracy of meters. And such precise measurements are very important, because they permit the determination of the effect of the Earth's gravitational field on the motion of the Moon, the effects of slight rotational motions of the Moon with respect to the Earth, and much more.

The creators of the "Lunokhod-1" vehicle had to overcome a number of design and operational problems — the vehicle had to operate reliably under specific conditions, over terrain with a relief characterized by depressions, cracks, rocks and ridges. Specific requirements were also placed on the control system: the distance between the control center and "Lunokhod-1" is about 400,000 kilometers! The kilometers covered over a broken terrain, the mass of scientific and technical information and the practical experience in controlling the movement of an automatic mobile investigator — these are far from complete results which confirm that the idea of using such vehicles is not only real, but is very promising for a systematic investigation of the Moon and planets. The "Luna-16" and "Luna-17" vehicles are essentially new types of automatic devices which are opening up truly unlimited possibilities.

But let's return to manned flights.

The launch of every manned spacecraft attracts the attention of the entire planet, and people of all countries of the world follow its course closely. The flight of a spacecraft is a complex scientific and technical experiment, in which thousands of people take part, and each such experiment means that mankind has gained yet another victory over the forces of nature, that another step forward has been made in the development of science and technology. It is on these basis that we must consider the unique scientific-technical and medical and biological investigations, and the experiments in the interests of the national economy of the country, which were carried out on board the "Salyut" orbital station.

Recently space flights have brought us considerably closer to the creation of orbital stations, to launches of automatic vehicles for deep systematic study of various regions of the universe, and to the creation of large laboratories and possibly entire cities in circumterrestrial space.

The distinguishing feature of the Soviet space program is its rush toward the future. Even now the base is being laid for a unique /113 space "bridge" which will provide an essentially new approach to future development of world cosmonautics.

We have attempted to cite several clear examples of the characteristic features of Soviet cosmonautics, to show its current level, to delineate the trends for further development, and to present those benefits which mankind may reap from space technology. Yes, even benefits, and therefore, everyone needs space now. The space vehicles of various countries have already visited space: the USSR, United States, England, France, Canada, West Germany, Australia, Italy, Japan and the Chinese Peoples Republic. Tens of countries are participating in joint experiments (within the framework of international cooperation and space programs). The developing countries are also being brought into this sphere. The experience

of space research during recent years demonstrates that there is presently not one country which is apparently not capable of itself implementing ever more valuable and technically feasible projects. This is all related to the enormous pecuniary investments and to the maximum input of the creative and productive efforts of people. It is for this reason that the role of international cooperation in space research will increase sharply in the near future. It will encompass a significantly greater number of countries, and will permit a more effective study and conquest of space. Cosmonautics will cross national boundaries more and more often, will be the basis for scientific and technical cooperation of different countries, and will contribute to a mutual understanding between the peoples of the world.

Again and again, we think about the enormous contribution of our contry to the investigation of space, about how the homeland of the Great October Revolution is leading world scientific and technical progress in this essentially important direction. The Soviet people are turning toward the Communist Party, are proud of the steadily growing might of Socialist economics, the rapid development of Soviet technology, and the increasing skills of our engineering-technical and working cadres.

Of course, we are still just learning how to derive specific benefits from space research. But the proper organization of investigations and rational utilization of those achievements of cosmonautics, which we now possess, will permit us even in the near future to change space into one of the most promising and profitable branches of the economy.

We have attempted to characterize present and future cosmonautics. Detailed analyses are superfluous at present, and they are usually debatable. But one thing is indisputable — space is necessary for man, and it will serve man for peaceful purposes.

The bridge to the future is being erected even today!

☆U.S. GOVERNMENT PRINTING OFFICE: 1973-739-155/74